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ABSTRACT

This report contains articles on research in kinesiology, the study of the principles of mechanics and anatomy in relation to human movement. Research on sequential timing, somatotype methodology, and linear measurement with cinematographical analysis are presented in the first section. Studies of the hip extensor muscles, kinetic energy, and individuality are included in the second section. A computer program for descriptive analysis of movements used during repeated performance of skills is explained. Motion simulation, using a three dimensional human form, is also presented. Each article presents figures and tables of data along with references. (BRB)

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Sequential Timing of Three Overhand Patterns

ACCORDING TO SEVERAL AUTHORS in the areas of mechanics and kinesiology — Broer (1), Broer and Houtz (2), Cooper and Glassow (3), and Wells (6) — there is similarity in the pattern of overhand movements. Broer states that throwing, a tennis serve, an overhead clear in badminton, and the smash in tennis and badminton are the same movement pattern in terms of mechanics. Indeed, the model in the photographic sequence in the Broer work does exhibit the same kind of pattern for the depicted overhand skills.

One of the investigators in the current study was interested in the mechanics of performance; the other was involved from the learning aspect, since it is a common practice in the teaching of new skills to relate them to patterns previously learned. With the emphasis in the literature on similarity of patterns and the assumed transfer of learning from one skill to another, it was projected that a comparison of several overhand patterns might indicate intra- and inter-individual similarities and differences. One of the investigators, Enberg (4), noted in a limited descriptive study that interindividual differences might be important considerations in the choice of descriptions for introducing new movement skills. Mechanically, since the musculoskeletal system limits the types of movement possible at each joint, similarities in patterning may result primarily from structure of the body rather than function for a given sport skill. More subtle differences may occur which are specific to the particular sport skill. Furthermore, this structure may be a reinforcer of one particular sport skill and serve to inhibit successful functioning for another sport skill.

The purpose of the present study was to make a comparison of intra-individual and interindividual performances on three overhand sports skills: the volleyball serve, the badminton smash, and the tennis serve. The portion reported here is part of a larger study now in progress.

Procedure

The subjects were three highly skilled college women: D.C. had competed on the intercollegiate level in all three sports, C.B. was a member of the intercollegiate teams in tennis and volleyball and an intermediate level player in badminton, and C.H. was a badminton player of international caliber, a member of the varsity volleyball team, and a novice at tennis.

The subjects were clad in leotard and tights, marked with standard tape markings at the joints, and taped with two spines, one at the upper spinal level, and the other at the sacral level.

Subjects were filmed on the same day, with a HyCam camera, from a distance of 70 feet, and at speeds of 730 to 775 frames per second. A timing device which operated

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The authors extend their gratitude to subjects Donna Chun, Cathy Burquist, and Carolyn Jensen Hein, to Barbara Fecht who contributed the drawings, and to Herbert Howard, research photographer at Washington State University.

at a constant 400 rpm was also included in the filming to aid in the identification of the frames. Each skill was repeated several times to insure that the subject was acquainted with the filming procedure and could achieve consistency in performance. The skill which each performer judged to be her best, i.e., badminton smash, volleyball or tennis serve, was filmed twice to allow for a comparison and to insure that the skill analyzed was not an isolated event but represented a typical performance. The films were analyzed while projected by a Recordak MPE-1 film reader. Tracings were made for the purpose of comparing the time involved and the sequential positioning in the various skills. It was felt that there would be disadvantages from the use of only one camera, but the advantages of the high speed of filming could provide an important addition to the literature in the description of the sequences of movement.

Findings

From Figure 1, (a five-tracing sequence of subject D.C. for each of three skills), a descriptive comparison may be made of segmental positioning from the moment of contact, backward in time at approximately .05 second intervals to .189 seconds before contact. In Figure 1A, at .189 seconds before contact, differences will be noted in the three stances, the amount of knee flexion, trunk inclination, and resultant angles of shoulder inclination. The differences in stance evolved from previous foot action which was: in the badminton smash, a definite step forward with the left foot during the stroke; in the volleyball serve, a planting of the left foot and continued forward movement of the unweighted right foot; and in the tennis serve, no step, but rather a dorsiflexion followed by planter flexion of both ankles. The trunk inclination in the volleyball and tennis serves appeared to occur as a result of the action of both knees and, to a lesser extent, both ankles. However in the badminton smash there were definite trunk positioning movements up to this point in the execution of the skill.

Figure 1B, at .136 seconds before contact, indicates the extent of shoulder, elbow, and wrist positioning. The body position for badminton and tennis was more upright in space; the volleyball position was lower because of prominent knee flexion. The shoulder inclinations for the tennis and badminton skills were similar. However the two skills that showed similar striking arm position were the badminton and volleyball. In the tennis stroke there appeared to be greater humeral outward rotation, resulting in a drop of the forearm and racket. The similarity of the tennis and badminton stance will also be noted. At this point in the sequences hip rotation for only the tennis stroke had progressed far enough into the backswing to remove the sacral spine from view.

Figure 1C, at .083 seconds before contact, indicates the extent to which knee and ankle action had altered the height of the body in space. Using the rectangular coordinate system, one would label the positions as a negative trunk inclination in the volleyball skill but a positive one for both the badminton and tennis. A noticeable feature was the elbow lead in badminton and tennis which was not yet present in the volleyball skill, the one with the shortest lever arm. Hip rotation had progressed evenly in the three skills, but the upper spinal rotation appeared to be less pronounced in volleyball than in the other two sport skills.

Figure 1D, at .034 seconds before contact, indicates a strong similarity in striking and balancing arm positions but also a difference in the angle of the body, and hence in the angle of projection of force. An analogy may be made between the position of the racket as a lever in the two implement sports and the position of the forearm as a lever in the volleyball skill. At this time the badminton racket had a greater distance to travel before contact than did the tennis racket. There may be implications here for timing of the sequence in relation to weight, length, or absence of a striking implement.

Figure 1E, at the moment of contact, indicates a similarity in badminton and tennis body positions but a difference in the angle of and point of contact with the projectile.

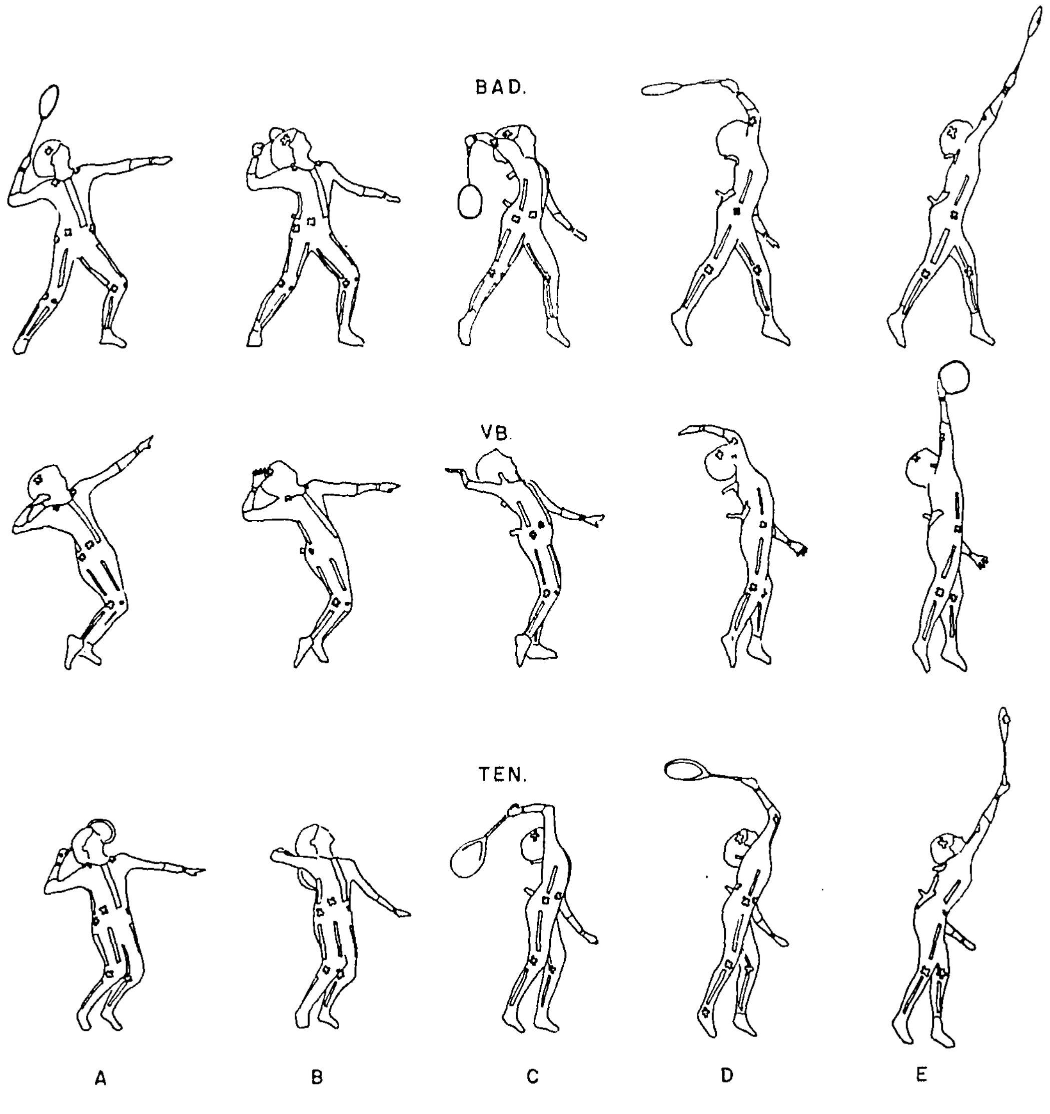

Figure 1. A film-tracing sequence of the badminton smash and the volleyball and tennis serves for subject D.C. A, .189 sec before contact (bc); B, .136 sec bc; C, .083 sec bc; D, .034 sec bc; E, contact.

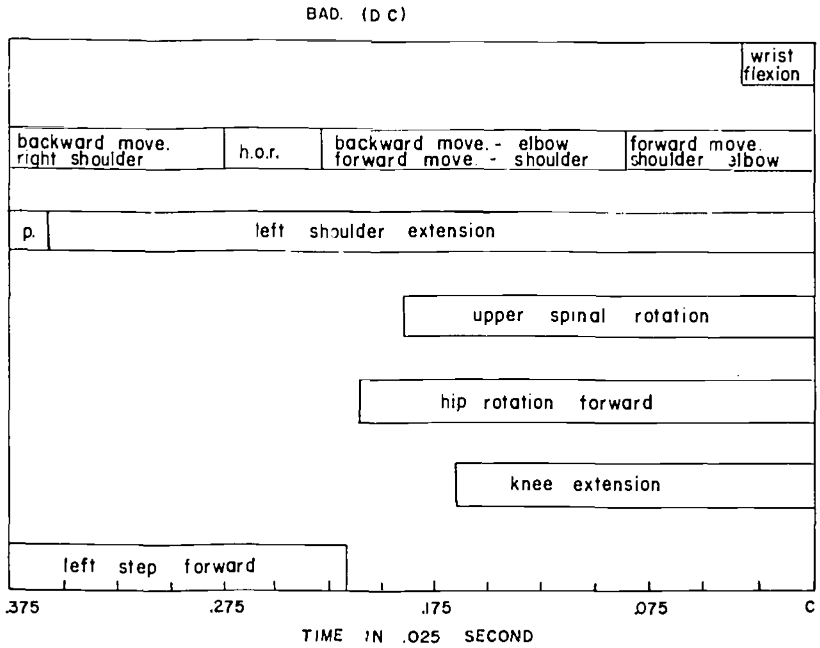

Figure 2. Segmental movements for the badminton smash from —.375 seconds until contact for subject D.C. P, pause in movement; h.o.r., humeral outward rotation; c, contact.

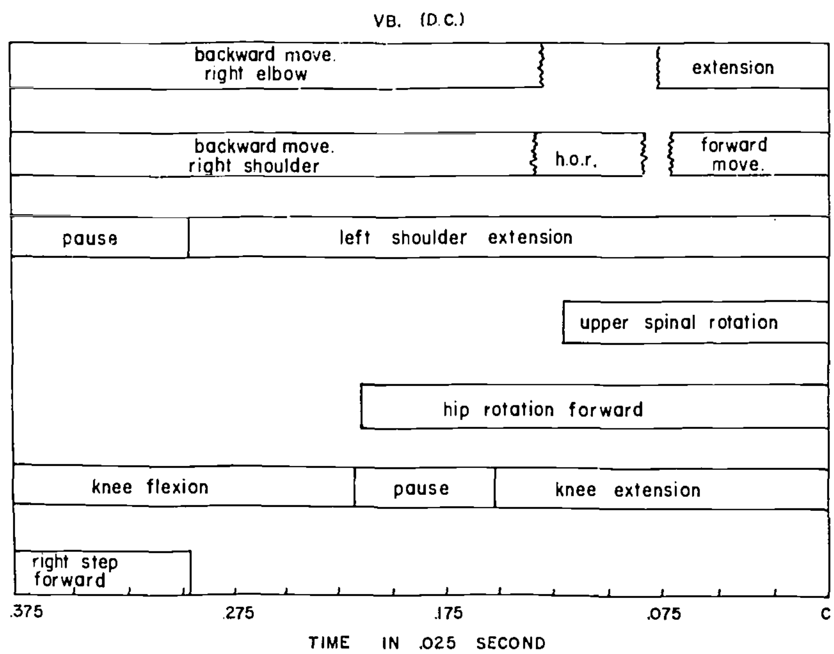

Figure 3. Segmental movements for the volleyball serve from —.375 seconds until contact for subject D.C. H.o.r., humeral outward rotation; c, contact; ( ), approximate time.

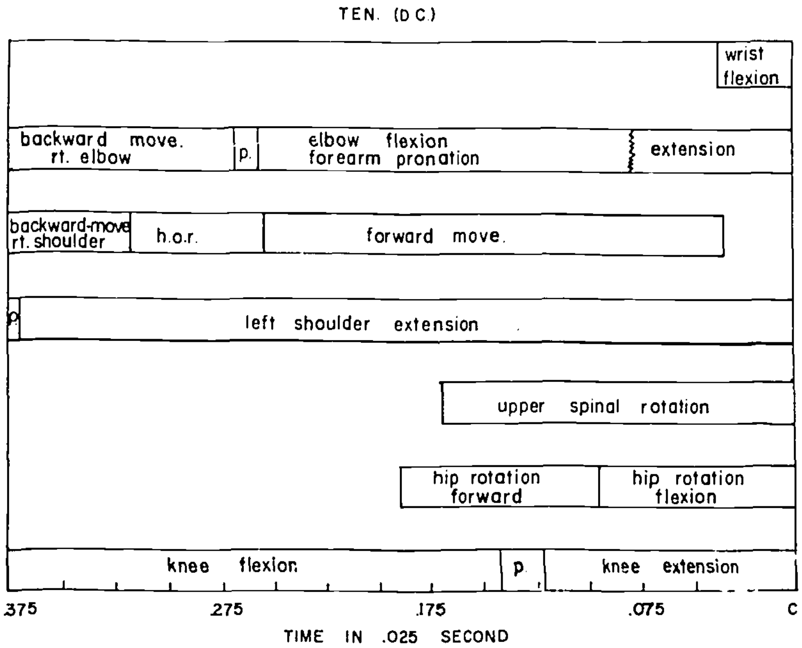

Figure 4. Segmental movements for the tennis serve from —.375 seconds until contact for subject D.C. P, pause; h.o.r., humeral outward rotation; c, contact; (⸗), approximate time.

The volleyball position was higher (no trunk flexion as in badminton and tennis) and more erect, and the point of contact was much closer to the gravitational line of the body than in the other two skills. Again, there may be implications about the influence of the purpose of the skill and the state of learning of the performer, as well as the influence of the striking implement, on segmental timing. The movement patterns of D. C., and particularly her body position at contact, were individualized for each of the skills.

In Figures 2, 3, and 4, the time sequences for the segmental movements are graphed for each of the three skills executed by D.C. These movements include only the force-producing phase of the skills. The time is from -.375 seconds until contact and represents an analysis often blurred in 64 fps filming and indiscernible to the human eye. In all three skills the -.375-second point in time is one in which the nonstriking arm approached the termination of the pause between flexing and extending.

Figure 2, the badminton time sequence, indicated that the establishment of the base of support (left foot forward) occurred just prior to pelvic rotation, typical of classical summation of force patterns. A combination of striking arm movement (right elbow and humeral outward rotation) was detected at —.227 seconds, or about .009 seconds before completion of the establishment of the base of support at —2.18 seconds. Both movements were followed closely by a hip rotation, detected at almost —.210 seconds before contact. Upper spinal rotation began shortly thereafter at —.185 seconds and was followed by knee extension at —.163 seconds. The onset of the final striking motion of arm and forearm at —.085 seconds and wrist at —.033 seconds were indicative of the velocity these segments must have attained prior to contact. It will be noted that the single camera led to some confounding of movements, but the number of frames per second still allowed a much finer analysis than has been previously reported.

Figure 3, the volleyball time sequence, indicated that the base of support (right foot forward) was established almost simultaneously with the beginning of the left arm action at —.300 seconds. Again, there were

TABLE 1. SEGMENT AND PROJECTILE VELOCITIES FOR SUBJECT D.C.

Activity	Elbow Extension	Wrist Flexion	Projectile Velocity
VB Serve	3015°/sec.		45.5 ft/sec.
BAD Smash	1619°/sec.	3748°/sec.	183.6 ft/sec.
TEN Serve	1371°/sec.	2743°/sec.	128.9 ft/sec.

positioning movements of the right, or striking elbow, but the hip rotation forward was the main detectable unwinding movement and occurred at —.217 seconds, very close to the same action in badminton. A difference in sequence was observed in comparison with the badminton skill. Here the knee extension at —.150 seconds preceded the upper spinal rotation at —.115 seconds. Therefore, the time span of the upper spinal rotation was less than that in badminton. The final forward movement was a combination of elbow and shoulder extension and humeral inward rotation beginning at about —.065. The latter movements were confounded, but the last movement was elbow extension. No wrist flexion was detected for this subject on the volleyball serve.

Figure 4, the tennis time sequence, indicates that there was no forward step involved in performance of this skill. The skill is otherwise similar to that of badminton in terms of order of segmental movement: hip rotation at —.190 seconds, upper spinal rotation at —.170 seconds, and knee extension at —.123 seconds. However, all of these movements occurred later in the total sequence, as if the tennis required a faster explosion. Hip flexion was detected at —.095 seconds and accompanied the continued hip rotation. Again, as in badminton, the final striking motion occurred with the elbow extension at —.080 seconds and wrist flexion at —.043 seconds.

Angular velocities of the segments for five frames (average of .006 seconds) prior to contact and projectile velocities were calculated for subject D.C. and are given in Table 1.

Although rotation occurred during various portions of the skills, there appeared to be no forearm rotation during the final .006 second, as determined by length of segment. Apparently the body, including the shoulder, was stabilized, and the movements occurring were elbow and/or wrist actions. Therefore the movements were basically in the anteroposterior plane and sufficiently parallel to the camera that measurements were accurate enough to report. It is assumed that any inaccuracies of reporting would be an underestimate rather than an overestimate of the velocities, since some translation did occur.

It is evident that the badminton smash and tennis serve represent high velocity projectiles, while the volleyball serve velocity was above average but not much above the minimum of 40 ft/sec. reported by Temple (5). However, since the elbow extension velocity was over 3000°/sec., the lower projectile velocity might be attributed to the coefficient of restitution of the volleyball, the short lever arm, or the performer's concern with accuracy and spin.

Since the findings reported here are only a portion of a larger study, the films for the other two subjects have not been analyzed in as great detail. However, some interesting comparisons arise in the positioning of the subjects at contact and at .034 seconds prior to contact. The tracings in Figures 5 and 6 are the equivalent of the last two tracings in Figure 1, i.e., drawings 1D and 1E. Figure 5A, at .034 seconds before contact, indicates that subject C.B. had a narrow stance which was similar for all three skills. The amount of knee flexion was minimal, but hip flexion was pronounced in all three skills. Again,

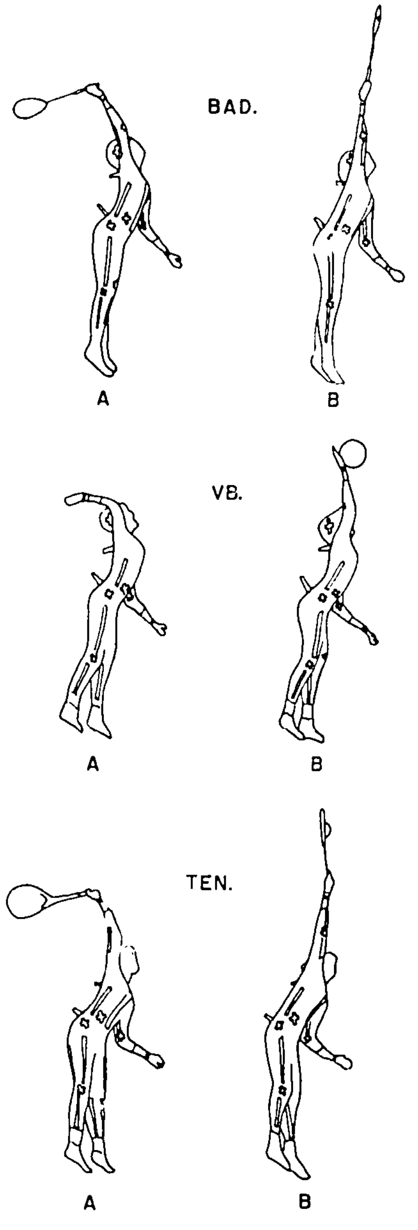

Figure 5. A film-tracing sequence of the badmin-ton smash and the volleyball and tennis serves for subject C.B. A, .034 sec before contact; B, contact.

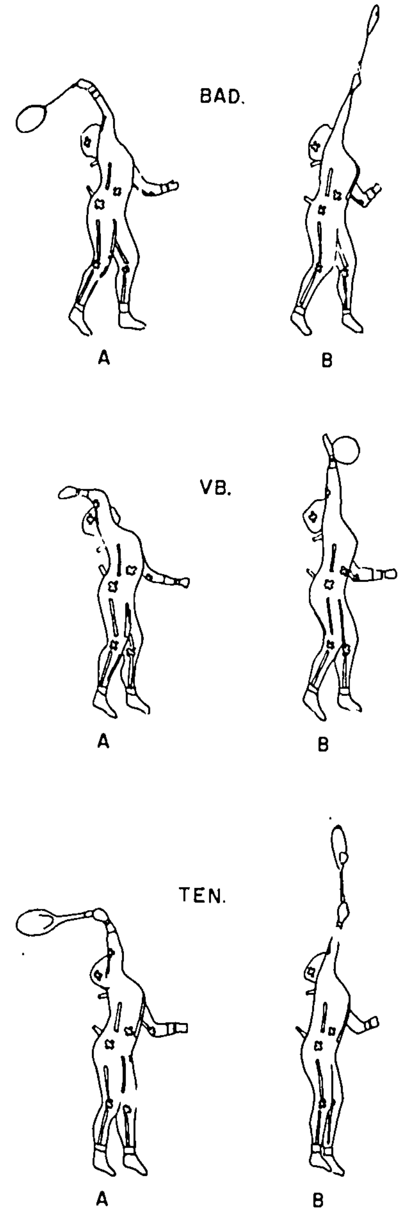

Figure 6. A film-tracing sequence of the badmin-tion smash and the volleyball and tennis serves for subject C.H. A, .034 sec before contact; B, contact.

the racket and forearm analogy suggested for D.C. applies, but the elbow flexion was more pronounced in the volleyball serve than for D.C. at this point in time. The kind of tennis serve (slice) probably accounted for the difference in the upper spinal rotation and head position in the tennis serve as compared with the other two skills. The right and left arm co-action was similar on all three skills.

Figure 5B indicates the similarity in the point of contact for all three skills with reference to the vertical line of the body. These points of contact differed, in terms of distance from the gravital line, from those of D.C. A somewhat exaggerated hip flexion at contact on all three skills was utilized by C.B., indicating that the trunk movement was an important part of her moment arm. C.B. still had a flexed elbow position, yielding a lower point of contact and a more upward flight of the projectile than for D.C. The trunk position for C.B. at contact in the tennis serve differed from that of the other two subjects and was necessitated by the kind of serve.

In Figure 6A, at .034 seconds before contact, C.H. exhibited less intra-individual differentiation that did either of the other two subjects. That finding might carry the implication that, as one skill reaches an extremely high level, similar movement patterns might actually replicate the one best skill. In the tracings, the stance, knee and hip flexion, amount of hip and spinal rotation, left and right arm action, and head position were very similar for all skills. It will be noted that the badminton racket was angled more sharply downward than the tennis racket. The major difference among the skills occurred in the amount of elbow and wrist flexion, with the volleyball elbow still flexed and the badminton wrist still cocked. The latter contributed to the velocity of the striking implement recorded later in the paper.

Figure 6B, point of contact, indicates differences in width of base of support, but the overall body positions were similar. The volleyball and badminton points of contact were closer to the gravital line of the body than that for badminton. This subject, like C.B., used hip flexion at contact on all three skills.

The velocity calculations for D.C. indicated a direct relationship between lever and projectile velocity. Therefore only the velocity of the final contributing lever was calculated for the other two subjects in this portion of the study. Because other factors, e.g., length of lever or coefficient of restitution of the striking surface in volleyball, might have affected the projectile velocity, calculations and subsequent comparisons of these velocities were not made. Wrist flexion was calculated for C.B. at 3432°/ sec. in badminton and 3977°/sec. in tennis. The volleyball elbow extension was 3165°/sec. The greatest velocity was achieved in her most proficient sport despite the fact that, theoretically, wrist flexion velocities with a badminton racket are faster than with a tennis racket. C.H. had slightly greater elbow extension velocity in volleyball, 3200°/sec. The slow wrist action of 2500°/sec. in tennis was indicative of C.H.'s novice status. However, the wrist flexion of this highly skilled badminton player was 6200°/sec., a figure which exceeds any published data. Cooper and Glassow reported wrist velocity for a highly skilled woman thrower at 5250°/sec. on an overhand throw, a skill without a striking implement.

Discussion and conclusions

The data presented indicate that there are some intra-individual and interindividual differences in the patterning of the three overhand skills discussed: the badminton smash, volleyball serve, and tennis serve. The differences in bodily movements may imply differences in neuromuscular patterning. An interesting question to pursue from the mechanics-learning aspect would be whether the neuromuscular system records pattern parts (loops or subroutines) which may be assembled either in a given order or with certain substitutions allowed in the chain, leading to different neuromuscular patterns.

Two overhand patterns are noted in the literature, and variations thereof were noted

in these data. One pattern involves a step forward followed by pelvic rotation and the classic unwinding sequences for force production. Another pattern introduces flexion in the anteroposterior plane, as a hip-trunk action and/or a knee-trunk action. Another question arising from these data would involve an investigation of the mechanical effectiveness of the two patterns. That is, is one pattern more effective for an individual, or is it more effective for a specific overhand pattern? And, more generally, will the anteroposterior pattern find more acceptance in the teaching of certain overhand skills?

The subject with a high degree of skill in all sports (D.C.) showed greater intraindividual differences in the contact position than did the other two subjects. For the subject who was very highly skilled in one sport in particular (C.H.), the position at contact in the other skills greatly resembled the contact position in the best sport. The slice serve in tennis for C.B. was responsible for some of the interindividual differences noted in that movement pattern.

On the basis of the data presented, it seems possible that the differences in performance of similar overhand patterns might be as important as the similarities, especially at the highly skilled level. In general, then, there are implications for transfer of learning as well as for mechanical improvement of performance. The results of the study indicate the need to pursue some of the questions evolving from the findings.

References

1. Broer, Marion R. *Efficiency of human movement.* (2d ed.) Philadelphia: W. B. Saunders Co., 1966.
2. ———, and Houtz, Sara Jane. *Pattern of muscular activity in selected sport skills.* Springfield, Ill.: Charles C. Thomas, 1967.
3. Cooper, John M., and Glassow, Ruth B. *Kinesiology.* (2d ed.) Saint Louis: C. V. Mosby Co., 1968.
4. Enberg, Mary Lou. *A comparison of two overhand patterns.* Unpublished report, Purdue University, 1966.
5. Temple, Ina. Developing skill in the overarm serve. In Betty Jane Wills (Ed.). *Volleyball guide.* Washington: American Association for Health, Physical Education, and Recreation, 1965, pp. 23-31.
6. Wells, Katharine F. *Kinesiology.* (4th ed.) Philadelphia: W. B. Saunders, 1966.

J. E. LINDSAY CARTER
BARBARA H. HEATH

Somatotype Methodology and Kinesiology Research

IT IS NOW THREE DECADES since Sheldon, Stevens, and Tucker (40) introduced the concept of somatotyping. This basic concept was unique and has proved useful in many fields of study during the past 30 years. In response to the need to overcome some inadequacies in the originally proposed system, a number of modifications to somatotyping have been developed. However, an examination of articles using the technique of somatotyping, and books in various disciplines describing the technique, reveals two problems: a) the authors in general seem to be singularly unaware of the developments and modifications in somatotype methodology; and b) inappropriate somatotype methods have been used for examining relationships between somatotype and other variables such as growth and motor performance.

The purpose of this paper is to describe the developments in somatotype methodology and to point out their relevance to kinesiological studies.

METHODS OF SOMATOTYPING

Sheldon's somatotype methods

Prior to 1940 the physique of an individual was usually characterized by individual or combined anthropometric measures or by grouping people into broad discrete categories or types on the basis of measures or visual impressions. There was a need for a classification of total body form on continuous scales which could be expressed in a simple value. A technique directed towards this end was described by Sheldon and others (38, 40), who called it "somatotyping," a term they defined as follows: ". . . a quantification of the three primary components determining the morphological structure of an individual expressed as a series of three numerals, the first referring to endomorphy, the second to mesomorphy, and the third to ectomorphy." Sheldon wrote that endomorphy, or the first component of the morphological level of the personality, is characterized by relative predominance in the bodily economy of structures associated with digestion and assimilation; mesomorphy, or the second component at the morphological level, by relative predominance of the mesodermally derived tissues, which are chiefly bone, muscle, and connective tissue; and ectomorphy, or the third component at the morphological level, by relative predominance of ectodermally derived tissues, which are chiefly skin and its appendages, including the nervous system. The somatotype, Sheldon holds, is a trajectory or pathway along which the individual is destined to travel under average conditions of nutrition and in the absence of major illness (38, p. 337).

Sheldon also used the terms morphophenotype, or the present body type, and morphogenotype, or the genetically determined body type. Nevertheless, Sheldon maintained that a given individual's somatotype is un-

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changeable, even though it can be assessed through inspection of a sequence of phenotypes through time. Sheldon's system introduced a seven-point rating scale for scoring the expression of each of the three components of a somatotype. The sum of the ratings on the three components is between 9 and 12. The system also contained tables of age corrections (at intervals of five years) for somatotype distributions ranging from 18 to 63 years, based on the height-weight ratio.*

In its earliest form the somatotype was determined from 17 measurements taken on a negative or photograph, but this laborious process was seldom used after its replacement with the photoscopic procedure. To assign a somatotype rating, Sheldon used somatotype photographs taken from the front, back, and side; a record of weights at various ages, where available; a table of the somatotype distribution according to the height-weight ratio and age of the subject; and standardized photographs and descriptions of the somatotypes against which to match each subject's photograph. Although the method appears simple enough, there are many subtleties, and satisfactory ratings cannot be achieved without considerable practice and training.

This new method of evaluating body form had its critics and the fact that it survived the somewhat acerbic but masterly critique of Howard V. Meredith (24) probably indicated the viability of the concept and at least laid the groundwork for future developments.

Sheldon (37, 39) recently summarized the main objections to his system: a) the somatotype changes; b) somatotyping is not objective; c) there are only two, not three, primary components; and d) somatotyping omits the factor of size. He offers comments on these criticisms and presents some information on further objectification of his method. Sheldon's "new" method, apparently in use since 1961 (36), is still inadequately described, and the associated tables have just been published (39). The essential procedures in the new method are as follows: a) standardized photograph and weight record are taken as before; b) maximal stature and minimal height-weight ratios are established from height and weight histories; c) a trunk index is derived from planimetric measurements of the thoracic and abdominal trunks as marked on the photographs; d) the somatotype is obtained from a table of height-weight ratios and trunk indices, then a second table of somatotypes plotted against maximal stature, and finally from the "basic tables" for somatotyping which combine the three parameters. These tables are age-corrected, and they are read differently for men and women, and the seven-point rating scale is retained. The sum of the three components is not limited to a range of from 9 to 12 as in the previous methods, but now ranges between 7 and 15. Whether or not these changes meet the objections to Sheldon's earlier system is quite debatable, as no supporting evidence is given by Sheldon. However, it is important to note that the trunk index system bears little relationship to his previous systems (38, 40) so must be regarded as another somatotype method. Furthermore, because maximal stature and minimal height-weight ratios are required for the trunk index system, its practical application in growth studies is questionable. To obtain this information would require testing annually until maximal stature is reached.

Hooton's somatotype method

Hooton's method (18) is essentially a phenotypic representation of the somatotype. He and his colleagues used this method extensively throughout the 1940's on United States Army men, and he based his ratings on inspection of the photograph and the height-weight ratio. When compared to Sheldon's 1940 method, the first component

* The height-weight ratio referred to is the height/cube root of weight (HWR). Strictly speaking, there are many height-weight ratios; one of these is the ponderal index which is the cube root of weight/height, and it is the reciprocal of this form, called the reciprocal ponderal index (RPI), which is used in somatotyping.

ratings in the lower grades were more "liberal," while the second component was rated more strictly, resulting in scores approximately one unit lower. The third component was derived directly from scaled height-weight ratios. The height-weight ratios of approximately 40,000 army men were divided into seven equal categories and the third component rating units were assigned directly. Hooton's system did not limit the sum of the three components to 9 through 12. Another departure from the Sheldonian system was the use of the terms fat, muscularity, and attenuation for the three component names (12, 18, 28).

Cureton's somatotype method (8, 9)

Cureton's system combines inspectional ratings of the photograph, palpation of the musculature, skinfold measurements, height-weight ratios, and assessments of strength and vital capacity. His studies were mainly concerned with young college men and athletes. Cureton stated his system ". . . will place any given case at the location in the Sheldon-Stevens-Tucker triangle at least closely enough for all practical purposes by objective measurements." (9, p. 15). However, his ratings differ from Sheldonian ratings in the third component. Cureton's ratings average close to one unit higher than would be possible by using Sheldon's height-weight ratio tables. In some of Cureton's samples of athletes the difference in ratings is even more marked; for example, the mean height-weight ratio for Danish gymnasts is given as 12.43, while the mean somatotype rating is 2½-5½-4 (9, p. 26). According to Sheldon's distribution of somatotypes by height-weight ratio (38, p. 267), the 3-5-4 somatotype has a height-weight ratio of 13.10. A height-weight ratio of 12.40 is optimum for a 3-6-1 somatotype. In regard to Cureton's inclusion of performance scores for assessing somatotype, such criteria are arbitrary and may lead to spurious relationships, because the component ratings are not independent of performance. Another difference in Cureton's use of somatotyping is that he constructs his somatotype triangle with ectomorphy on the left side and endomorphy on the right side of the triangle — a procedure which is opposite to that of all other authors.

Parnell's M.4 deviation chart method

Parnell (29, 31) suggested and developed the use of the following anthropometric measurements in conjunction with somatotype photographs to obtain component ratings: bone diameters, muscle girths, and skinfolds. These data were entered on the M.4 deviation chart, which included all necessary tables. The anthropometric somatotype thus obtained corresponded with Sheldon's estimate of somatotype, but Parnell substituted the terms fat, muscularity, and linearity (along with their respective abbreviations F, M, L) for the component names. The endomorphic estimate is derived from the skinfold measurements, the mesomorphic estimate from height, bone diameters, and limb girths, and the ectomorphic estimate from the height-weight ratio. Each of the component scales is corrected for different age groups. Although the chart is based on male data, it is also used for female ratings. Parnell developed similar M.4 charts based on anthropometric measures for children aged 7 and 11 (30, 31, 32).

Damon's anthropometric method

Damon, and others (10) predicted somatotype from anthropometric measurements on white and Negro soldiers, using a multiple regression technique. Forty-nine anthropometric measurements, including weight, lengths, breadths, depths, circumferences, skinfolds, grip strengths, and pulmonary function were used. Eighty percent of the predictions came within half a rating unit on a seven-point scale of the photographic ratings made by Damon (an experienced Sheldonian rater). Multiple correlation coefficients (R) for endomorphy, mesomorphy, and ectomorphy were .78, .66, .90 for whites, .83, .84, and .88 for Negroes. Up to 10 different measures were used to predict some of the components and the other component predictions were also used in some

of the equations. The grip strength scores and pulmonary function were not used in any of the equations.

Petersen's somatotype method for children

Out of a group of approximately 12,000 children, every child showing an illustrative or striking build was selected to be somatotyped. The children were mostly Dutch, with some Belgian children, undergoing school medical examinations. They ranged in age from approximately 5 to 14 years, with the majority prepubescent. The body build of these children was evaluated in accordance with what was actually seen in the photographs (a phenotype), without taking into consideration possible expectations with regard to future development. The somatoscopic criteria were those for Sheldon's young adult males, and the ratings were made by Petersen and Van Galen. The data presented is all cross-sectional and is the best published series of photographs on children's somatotypes. However, the author bases his general theme and orientation on Sheldon's concepts and believes in the constancy of physique, although he really avoids examining the issue in detail (33).

Medford somatotype equations

Equations for predicting somatotype components for boys 9 through 17 years of age have been examined as part of the Medford Growth Study conducted by the University of Oregon under the direction of H. Harrison Clarke. Sinclair (41, 42) and Munroe (26, 27) derived regression equations from anthropometric and performance measures for predicting somatotype components as rated by Heath (see below). A variety of equations are presented with the multiple regression correlations for the first and third component usually quite high, but with lower relationships for the second component. The prediction for the second component was improved whenever values for the other components were used in the regression equation. It was found that the regression equations were specific to the age at which the measurements were taken.

The Heath-Carter somatotype method

Heath (15) criticized certain limitations of Sheldon's method and described modifications designed to overcome these limitations. To begin with, the author stated that the seven-point scale was arbitrary and then proposed a rating scale, with equal appearing intervals, beginning theoretically with zero (but in practice at one-half) and having no arbitrary upper end point. Secondly, she saw no good reason for limiting the sum of the components ranging from 9 to 12, so this restriction was eliminated. Thirdly, she observed that in Sheldon's table of somatotypes and height-weight ratios there was a logical linear relationship between some ratios and somatotypes, but at other points the distribution seemed quite arbitrary. Heath then reconstructed the table to preserve a linear relationship throughout. Fourthly, Heath seriously questioned the "permanence" of the somatotype; therefore, she eliminated extrapolations for age and used the same height-weight ratio table for both sexes and all ages.

Heath's somatotype ratings were present somatotypes, or morphophenotypes, and were neither predictions of future somatotypes nor estimates of the somatotype at age 18, as were the Sheldonian somatotypes. The elimination of extrapolations for age strengthened somatotype methodology in several ways. The concept of a series of somatotypes for each individual replaced that of one somatotype for a lifetime. In growth studies it was possible to study the evolution of adult somatotypes from a succession of pre-adult somatotypes. Furthermore, subjects in a reference population, but with different ages, could be compared directly, as they were measured on the same measuring scale. In the past 12 years Heath has applied these modifications to somatotype data involving approximately 15,000 ratings used in over 30 published studies.

Heath and Carter (17) further objectified Heath's system by incorporating Parnell's M.4 technique. Heath and Carter define the somatotype as "*present morphological conformation.*" This somatotype is expressed by a three-numeral rating of the

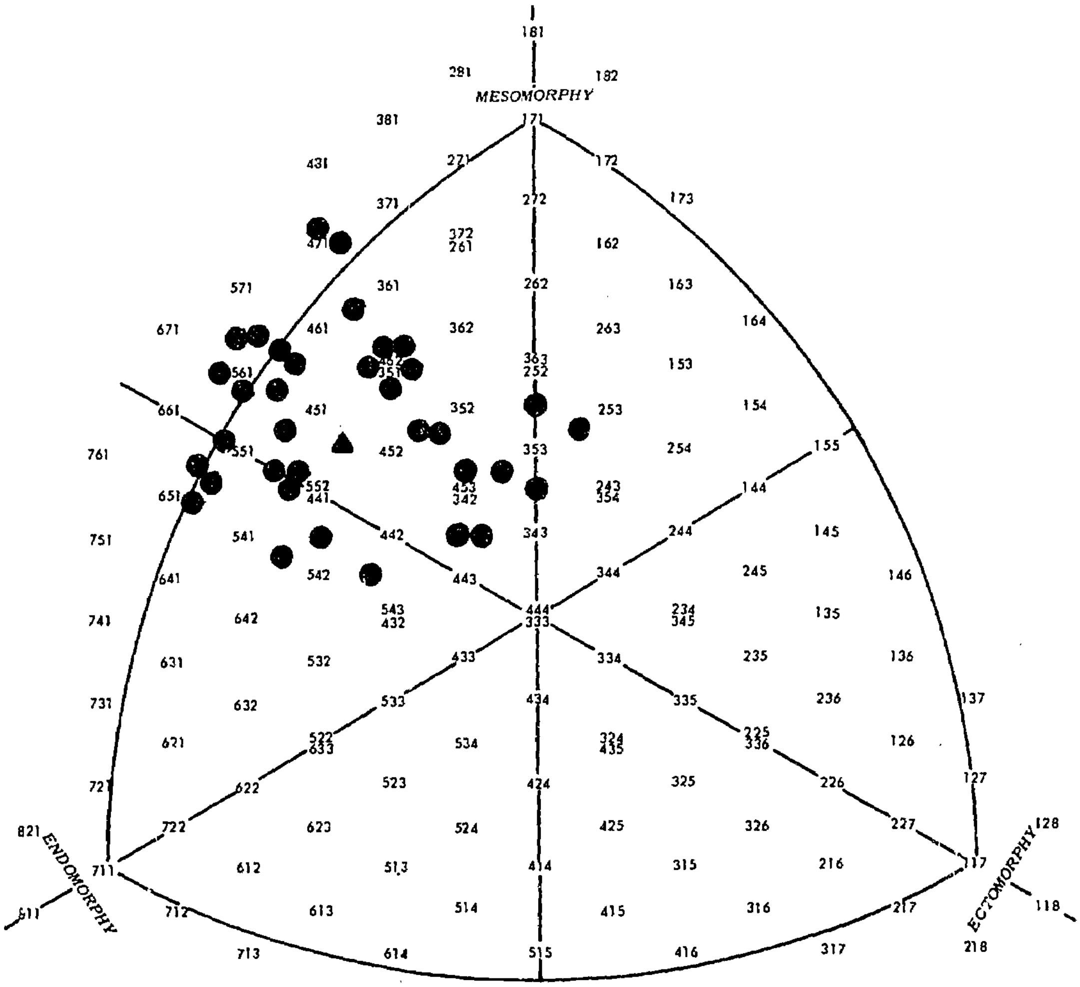

Figure 1. Somatochart showing distribution of the somatotypes of 35 San Diego State College football lettermen. Somatotype ratings were made using Parnell's M.4 Deviation Chart method. The mean somatotype (triangle) is 4.7–5.5–2.1.

three primary components of physique which identify individual features of body morphology and body composition. The first, or endomorphic component, refers to relative musculo-skeletal development for the individual's height. (It may be thought of as relative lean body mass). The third, or ectomorphic component, represents relative linearity of individual physiques. Its ratings, derived largely but not entirely from height-weight ratios, evaluate body form and longitudinal distribution, or "stretched-outness" of the first and second components. Extremes in each component are found at both ends of the scales. That is, low first component ratings signify physiques with little nonessential fat, while high ratings signify high degrees of nonessential fat. Low second component ratings signify light skeletal frames and little muscle relief, while high ratings signify marked musculo-skeletal development. Low third component ratings signify great mass for a given height and low height-weight ratios, while high ratings sig-

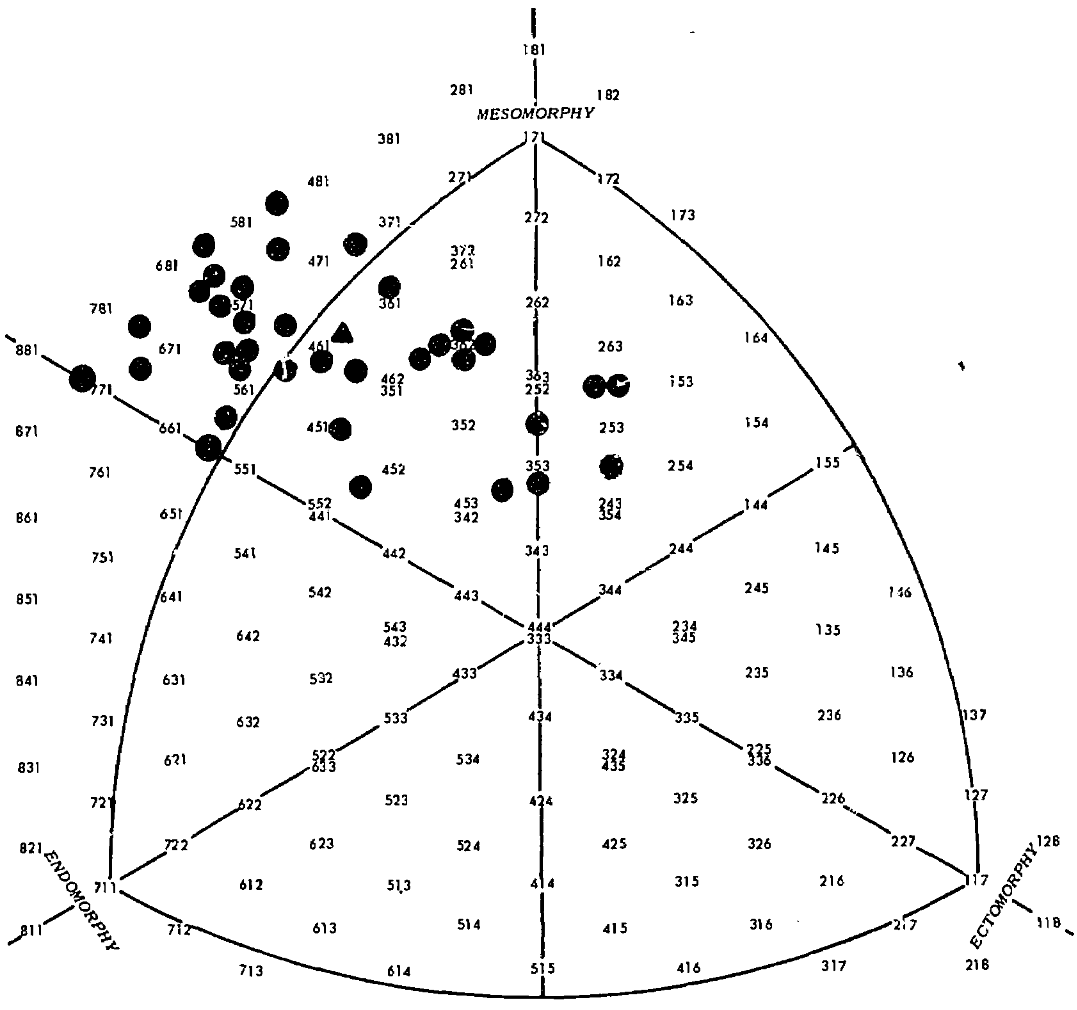

Figure 2. Somatochart showing distribution of the somatotypes of 35 San Diego State College football lettermen. Somatotype ratings were made using the Heath-Carter Anthropometric somatotype method. The mean somatotype (triangle) is 4.2–6.3–1.4.

nify linearity of body segments and of the body as a whole (little mass for a given height), together with high height-weight ratios.

For the assessment of somatotypes by means of the Heath-Carter method, the following data are needed: height, weight, four skinfolds (triceps, subscapular, suprailiac, calf), two bone diameters (humerus, femur), two muscle girths (flexed arm, calf), information on age, and a revised height-weight ratio table. By entering data on the Heath-Carter somatotype rating form the anthropometric somatotype is obtained directly. Details of this procedure are fully explained elsewhere (17). The Heath-Carter anthropometric somatotype rating relates very highly with the criterion rating by Heath. However, a final somatotype rating based on both the photograph and anthropometric somatotype is determined by these two sources of data and the distribution of somatotypes for the given height-weight ratios. For those trained in the method, a

rating may be made from the photograph and the height-weight ratio table.

In addition to the above methods, Hunt (19) warns us of idiosyncratic rating methods — these methods develop when different raters (simply because they are different people) place different interpretations on the criteria for the components, in making subjective photographic ratings.

It can be seen from the descriptions of the various methods above that they differ with respect to the basic premise of whether or not the somatotype rating is an attempt at assessing the constitutional and unchanging pattern of somatotype, or whether it is a phenotypic (i.e., present) estimate of the somatotype. The estimates of the components are based on one or more combinations of photoscopic estimates, planimetry, anthropometry, and functional performance. When using any of the above methods the validity of the method, the reliability and objectivity of the ratings, and the measurement used in the ratings are integral parts of a study.

Obviously, somatotype ratings calculated by various methods are likely to be different. For information as to the magnitudes of the differences between methods and relationships between them, the reader is referred to the following studies (10, 11, 12, 14, 15, 16, 17, 19, 21, 23, 25, 26, 27, 28, 29, 31, 34, 44).

As illustrations of the differences between methods, two examples are given. In Figures 1 and 2 the same group of football players (4, 5) are somatotyped by Parnell's M.4 deviation chart method (Figure 1), and by the Heath-Carter anthropometric method (Figure 2). Comparison of both the mean somatotypes and the distributions on the somatocharts shows considerable differences between the two groups. One particularly noticeable effect is the compressing of all somatotypes with a mesomorphy rating of 7, 7½, or 8 by the Heath-Carter method onto a 7 rating, which is maximum for the M.4 method. This lack of discrimination at

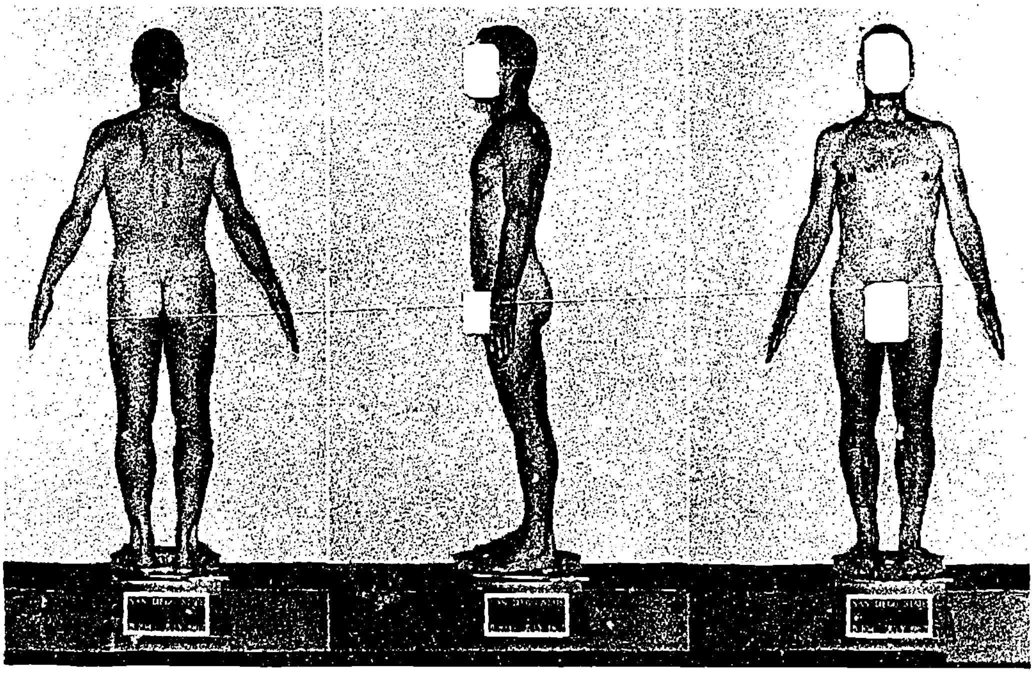

Figure 3. An individual somatotyped by four different methods. Age = 54.3 yrs.; height = 67.6 in.; weight = 145.5 lbs.; height-weight ratio = 12.84. Heath-Carter Anthropometric somatotype, 2½–6½–2½; Heath-Carter Photoscopic plus Anthropometric somatotype (authors' independent ratings agreed), 2–6–2½; Sheldon's Trunk Index somatotype, 2½–4–3½; and Parnell's M.4 Deviation Chart somatotype, 2½–6½–4.

the upper end of the scale has forced a lower mean somatotype rating by the M.4 method for mesomorphy compared to the Heath-Carter method.

A second example is given in Figure 3 in which a middle-aged male is rated by the Heath-Carter anthropometric method, the Heath-Carter photoscopic method, the Sheldon's trunk index method, and by the M.4 method. Only the two Heath-Carter ratings are similar on all three components. The other two ratings are dissimilar from each other and from the Heath-Carter ratings, especially for the second and third components.

The essential point to be gained thus far is that there are different methods of somatotyping, and that the relationships between these methods are generally known. Thus, the word somatotyping is a generic term embracing a number of different methods.

THE RELEVANCE OF SOMATOTYPE METHODOLOGY TO KINESIOLOGY STUDIES

The choice of the method of somatotyping in kinesiological studies is determined largely by the purpose of the study. In general, we are looking for structure-function relationships; therefore if we measure performances at a given time (and perhaps again at a later time), then it would seem logical to relate these performances to the somatotype ratings at the same time. With respect to the ratings, two simple criteria are applicable: a) the rating method should be independent of the functional measurements; and b) the ratings should be allowed to vary for the individual. The appropriate methodology, therefore, is one in which the ratings are based on present somatotypes (i.e., they are not age-corrected or presumed to be constant), and the performance scores are not part of the rating method. In growth studies, just as it is important to record absolute values such as height and weight on the same scales at different points in time, it is equally important to rate somatotype components in the same manner so that distance and velocity curves may be plotted.

If, on the other hand, we merely wish to identify the subjects as belonging to a particular somatotype group, then the use of a fixed or permanent somatotype rating may be useful. In this case, the rating should be regarded as one would regard blood groups, or ethnic classification. This procedure would appear to have little to recommend it because of its limited usefulness in structure-function studies. Furthermore, the genetic basis of somatotype has never been proven or even the possible magnitude of it established. In spite of Sheldon's statements to the contrary (37, 39), for which he presents no supporting data, the majority of the evidence in growth and development studies is overwhelmingly in the direction of plasticity and inconstancy and somatotype values (1, 2, 3, 6, 7, 13, 20, 21, 22, 25, 26, 27, 28, 35, 41, 42, 43). Of course, the results of such studies themselves depend on the specific methodology used. If one wishes to prove that somatotype is constant from age to age, one merely has to shift the scales for each age group, as is done in the Sheldonian system and in Parnell's M.4 system. In these systems, different "looking" amounts of the components at different ages are given the same rating.

In summary, then, we have seen that there are several distinct somatotyping methods which have different bases and meaning. Because of these differences, several questions need to be answered: a) What method of somatotyping is to be used? b) Is the method appropriate to the problem? c) Who is to do the ratings and what is his reliability? In kinesiological studies the use of a method which is not age-corrected, and is based on a scale which reflects changes in somatotype, is recommended.

That certain important and substantial relationships have been shown between somatotype components and structural and functional variables is encouraging, and although different systems with different meanings have been used this does not obscure the fundamental fact that such associations do exist. An understanding of the different methodologies may help us to clarify some of the relationships and to discover others.

References

1. Barton, W. H., and Hunt, E. E., Jr. Somatotype and adolescence in boys: A longitudinal study. *Human Biology* 34:254-70, 1962.
2. Bodel, J. K., Jr. *Distribution and permanence of body build in adolescent boys.* Doctoral dissertation, Harvard University, 1950.
3. Carter, J. E. L. *An analysis of somatotypes of boys aged twelve to seventeen years.* Master's thesis, State University of Iowa, 1958.
4. ———. Somatotypes of college football players. *Research Quarterly* 39:476-81, 1968.
5. ———. Somatotype characteristics of champion athletes. *Proceedings of the Anthropological Congress, Praha-Humpolec.* Czechoslovakian Academy of Science, September 1969.
6. ———, and Phillips, W. H. Structural changes in exercising middle-aged males during a 2-year period. *Journal of Applied Physiology* 27:787-94, 1969.
7. Clarke, H. H. (Ed.). *The Medford, Oregon, Boy's growth study. Curriculum Bulletin* No. 238, University of Oregon, Eugene, Oregon, November 1963.
8. Cureton, T. K., Jr. *Physical fitness, appraisal and guidance.* London: Henry Kimpton, 1947, Ch. 11.
9. ———. *Physical fitness of champion athletes.* Urbana, Ill.: University of Illinois Press, 1951.
10. Damon, A., and others. Predicting somatotype from body measurements. *American Journal of Physical Anthropology* 20:461-74, 1962.
11. DeWoskin, S. F. *Somatotypes of women in a fitness program.* Master's thesis, San Diego State College, 1967. (University of Oregon Microcard PE 1007)
12. Dupertuis, C. W., and Emanual, I. *A statistical comparison of the body typing methods of Hooton and Sheldon.* WADC Tech. Report 56-366, ASTIA Document AD97205. Wright Air Development Center, U.S. Air Force, Wright Patterson Air Force Base, Ohio, 1956.
13. Garn, S. M. The somatotyping of young children. I. Standards. II. Constancy of the ratings. (Proceedings of the Nineteenth Annual Meeting of the American Association of Physical Anthropology) *American Journal of Physical Anthropology* 8:261, 1950.
14. Haronian, F., and Sugarman. A. A. A comparison of Sheldon's and Parnell's methods for quantifying morphological differences. *American Journal of Physical Anthropology* 23:135-42, 1965.
15. Heath, B. H. Need for modification of somatotyping methodology. *American Journal of Physical Anthropology* 21:227-33, 1963.
16. ———, and Carter, J. E. L. A comparison of somatotype methods. *American Journal of Physical Anthropology* 24:87-99, 1966.
17. ———. A modified somatotype method. *American Journal of Physical Anthropology.* 27:57-74, 1967.
18. Hooton, E. A. *Handbook of body types in the United States Army.* Cambridge, Mass.: Department of Anthropology, Harvard University, 1951.
19. Howells, W. W. *Variation of external body form in the individual.* Cambridge, Mass.: Peabody Museum, Harvard University, 1957.
20. Hunt, E. E., Jr. A note on growth, somatotype, and temperament. *American Journal of Physical Anthropology* 7:79-89, 1949.
21. ———, and Barton, W. N. The inconstancy of physique in adolescent boys and other limitations of somatotyping. *American Journal of Physical Anthropology* 17:27-36. 1959.
22. Lasker, G. W. The effects of partial starvation on somatotype: An analysis of material from the Minnesota starvation experiment. *American Journal of Physical Anthropology* 5:323-41, 1947.
23. Livson, N., and McNeill, D. Physique and maturation rate in male adolescents. *Child Development* 33:145-52, 1962.
24. Meredith, H. V. Comments on "Varieties of Human Physique." *Child Development* 11: 301-309, 1940.
25. Morton, A. R. *Comparison of Sheldon's trunk-index and anthroposcopic methods of somatotyping and their relationships to the maturity, structure, and motor ability of the same boys nine through sixteen years of age.* Doctoral dissertation, University of Oregon, 1967. (Microcard PE 1032)
26. Munroe, R. A. *Relationship between somatotype components and maturity, structural, strength, muscular endurance, and motor ability measures of twelve-year-old boys.* Doctoral dissertation, University of Oregon, 1964. (Microcard Psy206)
27. ———; Clarke, H. H.; and Heath, B. H. A somatotype method for young boys. *American Journal of Physical Anthropology* 30:195-201, 1969.
28. Newman, R. W. Age changes in body build. *American Journal of Physical Anthropology* 10:75-90, 1952.
29. Parnell, R. W. Somatotyping by physical anthropometry. *American Journal of Physical Anthropology* 12:209-239, 1954.
30. ———. Physique and mental breakdown in young adults. *British Medical Journal* 1:1458, 1957.
31. ———. Behaviour and physique. London: Edward Arnold, 1958.
32. Parnell, R. W., and others. Physique and the grammar school entrance examination. *British Medical Journal* 1:1506-10, 1955.
33. Petersen, G. *Atlas for somatotyping children.* Springfield, Ill.: Charles C. Thomas, and Assen, the Netherlands: Royal Vangorcum, 1967.
34. Roberts, D. F., and Bainbridge, D. R. Nilotic physique. *American Journal of Physical Anthropology* 21:341-70, 1963.
35. Seltzer, C. C., and Gallagher, J. R. Somatotypes of an adolescent group. *American Journal of Physical Anthropology* 4:153-68, 1946.
36. Sheldon, W. H. *New developments in somatotyping technique.* Lecture delivered at Children's Hospital, Boston, Massachusetts, March 13, 1961.
37. ———. *A brief communication on somatotyping, psychiatyping and other Sheldonian delinquencies.* Paper read at the Royal Society of Medicine, London, May 13, 1965.

38. ———: Dupertuis, C. W.; and McDermott, E. *Atlas of men*. New York: Harper and Bros., 1954.

39. Sheldon, W. H.; Lewis, N. D. C.; and Tenney, A. M. *Psychotic patterns and physical consition*. Invitation lecture, Eastern Psychiatric Research Association Symposium, New York, November 16, 1968.) In Schizophrenia, current concepts and research. Hicksville, N. Y.: D. V. Siva Sankar, PJD Publications. (In press)

40. Sheldon, W. H.; Stevens, S. S.; and Tucker, W. B. *The varieties of human physique*. New York: Harper and Bros., 1940.

41. Sinclair, G. D. *Stability of physique types of boys nine through twelve years of age*. Master's thesis, University of Oregon, 1966. (Microcard PE 833)

42. ———. *Stability of somatotype components of boys ages twelve through seventeen years and their relationships to selected physical and motor factors*. Doctoral dissertation, University of Oregon, 1969. (Microcard PE 1042)

43. Tanner, J. M. The effect of weight training on physique. *American Journal of Physical Anthropology* 10:427-62, 1952.

44. ———. Reliability of anthroposcopic somatotyping. *American Journal of Physical Anthropology* 12:257-65, 1954.

ERNEST W. DEGUTIS

A Problem Solving Approach to the Study of Muscle Action

IT IS COMMON PRACTICE for physical education majors, in their study of the human body, to put considerable emphasis on the study of the skeletal, or voluntary, muscular system. The emphasis is justifiable since the skeletal muscular system: a) makes up over 40 percent of the total body weight; b) by virtue of its contractile properties, produces movement for utilitarian, recreative, and affective (expressive) purposes; c) contains kinesthetic-proprioceptive sense organs which, from one point of view, render muscle as man's most important sensory mechanism; and d) is critical to the development of the various organic systems because of the supportive role of these organic systems in muscular activity.

One aspect of skeletal muscular system study includes its gross structure. Invariably, the study of gross structure involves a detailed description of many of the body's muscles in terms of each muscle's attachment and the movements the muscle is purported to produce when it contracts. Learning points of attachment and movements or actions attributed to contracting muscles calls for considerable unattractive memorization. The problem of dealing with a new vocabulary, the extensiveness of the information with its similarities and differences, and the infinite detail can make the study of muscles and muscle actions a tedious, burdensome, and difficult chore. Consequently, many students are likely to lose interest. This is unfortunate, as the subject is important in itself and is fundamental to the student's professional preparation, since such knowledge is related to the ability to deal satisfactorily with content in other courses (e.g., kinesiology, physiology of exercise, athletic training).

Most teachers are aware of the shortcomings of rote learning. When the attempt to learn is obstructed by unattractive, boring memory work, searching questions should be asked regarding methods. This is especially true if waning interest, low level motivation, and underachievement are in evidence. Thoughtful questions directed to the evaluation of methodology might include the following: Is there concern for the mastery of principles, or only for the mastery of limited content which seems to lack significance and is readily forgotten? Is the student challenged in a stimulating way? Is the student's curiosity aroused, his appreciation deepened, and his motivation heightened? Does the experience contribute to the student's ability to "learn to learn"? Is the overall experience satisfactory? Is it productive? Affirmative responses to these questions are consistent with a method that has much to commend it.

Various methods may be employed in the study of movements or actions purportedly produced by contracting muscles. A good way to initiate such study is through a problem solving approach, herein termed "mus-

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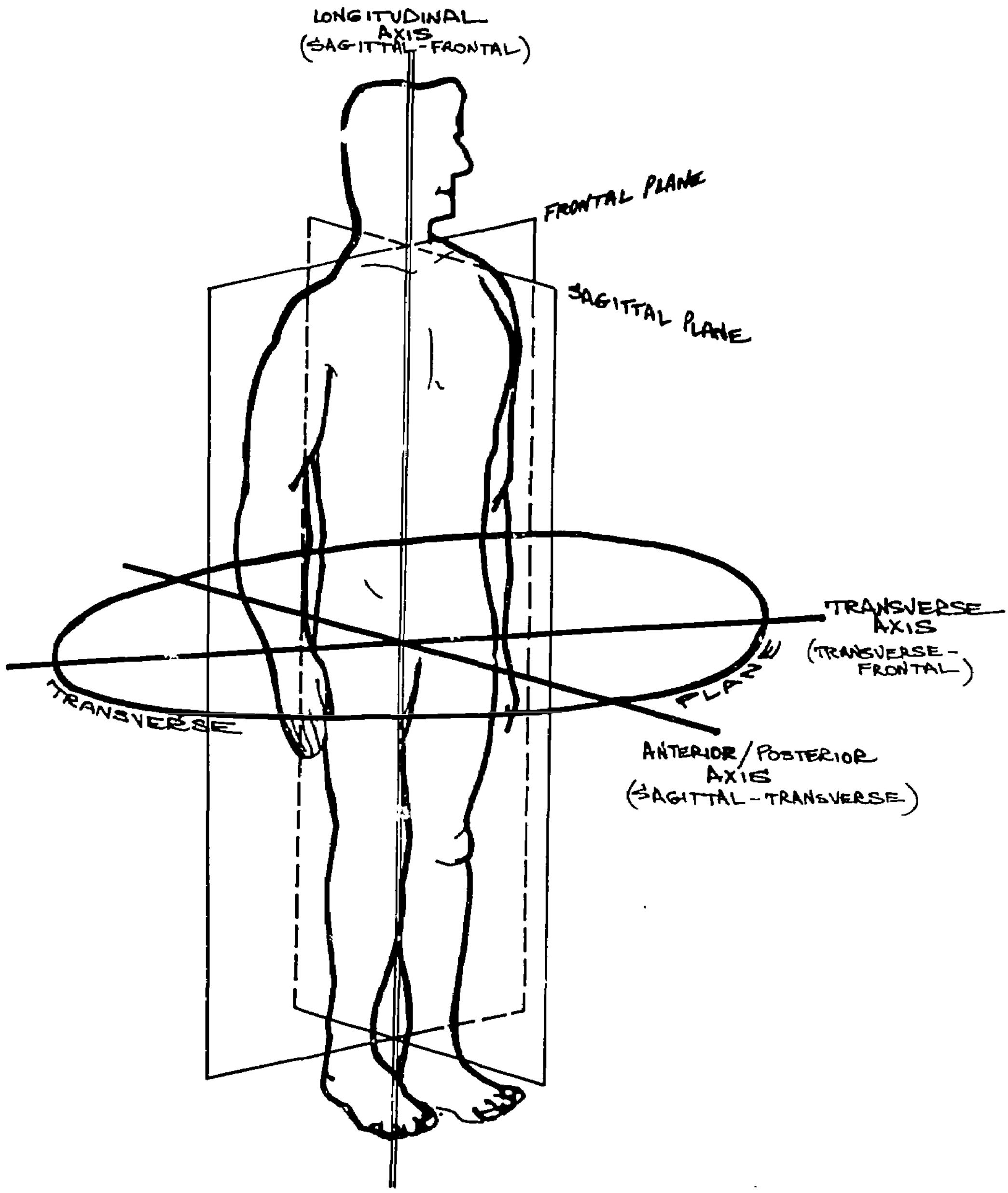


Figure 1. Fundamental body and movement planes (sagittal, frontal, and transverse), and fundamental motion axes (transverse, anterior-posterior, and longitudinal). When an axis is named by the planes in which it lies, the following applies: longitudinal or frontal-sagittal axis; transverse or transverse-frontal axis; and anterior-posterior or transverse-sagittal axis.

cle action analysis" (MAA).* This method has the potential for eliminating many of the undesirable concomitants of the rote learning approach. The study of muscle points of attachment necessarily receives emphasis in MAA but it becomes subordinate to the mechanical principles underlying the "how" and "why" of muscle action. In other words, MAA enables the student to develop a rationale for explaining the movements produced by the contraction of a muscle or a muscle group. It is not satisfactory to simply state that a muscle may act in flexion or in any other movement. The reason must be stated in terms of the muscle's line of force or pull, and the positional relationships of the muscle's line of force to the motion axis upon which it is acting. Thus muscular action, in the mechanical sense, must be reasoned out. The invariably favorable response of students who have used the MAA problem solving approach to muscle study permits the enthusiastic endorsement of this method. The intent of this paper is to describe the MAA method and the essence of the preparatory procedures by which this method may be satisfactorily implemented.

Preparatory learning experience, for muscle action analysis (MAA)

It has been found that the MAA method can be efficiently and successfully implemented if preparatory learning experiences of the type described herewith are provided for the student. Attempts to implement this method without such experience have not been as satisfactory.

1. A study of pertinent information relative to some basic anatomical considerations: a) identifying and defining fundamental body and movement planes, and fundamental motion axes (Figure 1); b) anatomical terms of direction or position; and c) anatomical movements. (Note: In this text, it is understood that all movements are initiated from the anatomical position.)

2. A study of the skeletal system, which results in a thorough familiarity with the surface markings on bones which serve as points of attachment for muscles.

3. A study of the arthrodial system which stresses the functional and structural classification of joints. The structural classification of joints is based primarily on the absence or presence of a joint cavity (the continuity or discontinuity of skeletal parts). The functional classification of joints is based on the number of motion axes about which the joint admits movement and, therefore, the number of planes in which movement can occur. Considerations common to specific joint actions would further include the identification of the motion axis or axes involved, and the naming of anatomical movements and the planes in which movements occur.

4. A study of selected mechanics related to leverage and force, since MAA basically involves the application of leverage and force principles. It is especially important for students to comprehend that a muscle's line of force or pull, when applied at an acute angle (and therefore coursing obliquely) to a skeletal part and at a distance from its motion axis, has two components acting at right angles to each other, and each acting on the motion axis to produce angular motion (Figure 2). Otherwise, a line of force which is applied at a right angle to a skeletal part and acts to produce angular motion has a direct, single pull or line of action (Figure 3).

5. The development of the "movement producing combination" concept, wherein angular movement, in a mechanical sense, is recognized as a function or a combination of two factors: a) the direction of the line of force, and b) the line of force's positional relationship to the motion axis.

Students have little difficulty in understanding the movement producing combination (MPC) concept if the approach is made by use of the wheel and axle principle. An improvised wheel and axle of sorts can be used to demonstrate what the students already know, i.e., if a wheel is to turn on its axis (angular motion), a force must be applied to the wheel at a distance from the

* MAA is a modified form of a method long used in the Department of Anatomy at the University of Wisconsin.

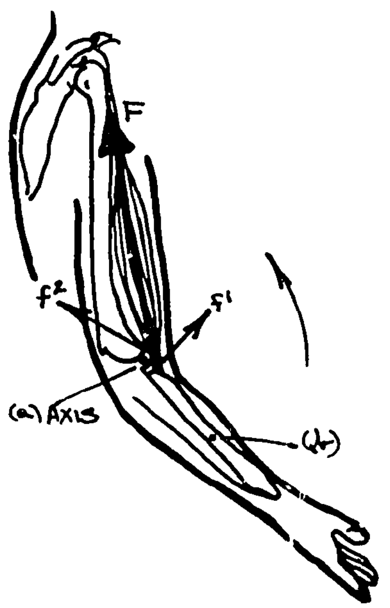


Figure 2. Schematic illustration of the two components of force (f_1, f_2) of a muscle's obliquely coursing line of pull (F), both acting on a skeletal part (b) to produce angular motion about a motion axis (a) located at the center of the joint cavity.

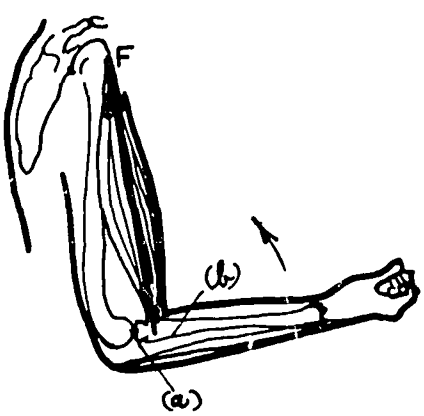


Figure 3. Schematic illustration of the line of force (F) of a muscle acting at a right angle to a skeletal part (b), which produces angular motion about an axis (a) by its single, direct line of pull.

axis and in a plane that is perpendicular to it. This should be demonstrated with the wheel positioned in each of the three fundamental movement planes. In order to identify movement producing combinations the wheel, as it is positioned in each of the three planes, must be spatially oriented in terms of anatomical directions to show in what direction the turning force is acting, and what is the relationship of the line of force, positionally speaking, to the motion axis.

Generally, students have little or no difficulty in their understanding up to this point. The problem comes in their attempt to transfer the wheel and axle and the MPC concepts to the body and visualize them operationally. For example, if these concepts are perceived in the body context there should be recognition that when the wheel is positioned in the sagittal plane and its motion, therefore, occurs in that plane, flexion (Figure 4a-b) and extension (Figure 4c-d) movements are being considered. Figure 4e illustrates the importance of understanding the positional relationship of the line of force to the motion axis. In Figure 4e, the lines of force, F and F_1, act in the same direction, superiorly and posteriorly. However, force F has anterior and superior relationships to the motion axis as indicated by its components f_1 and f_2, respectively. Force F_1 has inferior and posterior relationships to the motion axis as indicated by its components, f_3 and f_4. Forces F and F_1 will both produce motion in the sagittal plane but in opposite directions. Figure 4f expresses the same concept but with the lines of direction of forces F and F_1 reversed. The MPC concept related to flexion-extension movements occurring about the transverse axis and illustrated in Figure sequence 4a–f, is similarly illustrated in Figure sequence 5a–f for abduction-adduction movements about an anterior-posterior axis, and in Figure sequence 6a–f for medial and lateral rotation movements which occur about the longitudinal axis.

Some students grasp the concept under consideration in its body context very readily. For these students, muscle study from the standpoint of MAA can be a captivating challenge. Others have more diffi-

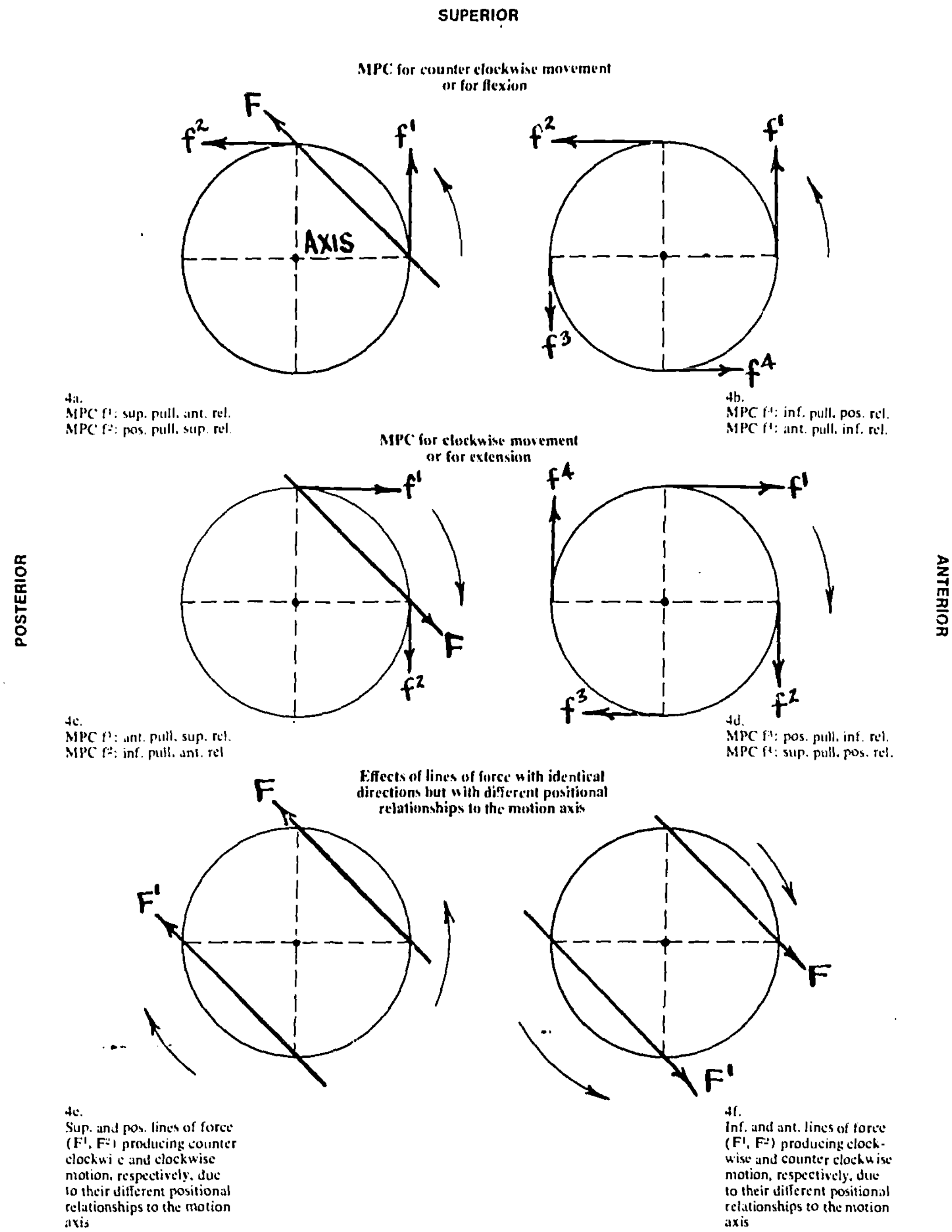


Figure sequence 4a–f. Identifying MPC in the sagittal plane. The spatial orientation as shown is common to all diagrams and allows: a) for the determination of the directions of the line of force, and b) for the positional relationships of the lines of force to the transverse motion axis, represented as a point within the wheel. In the body context, sagittal plane movements are flexion and extension.

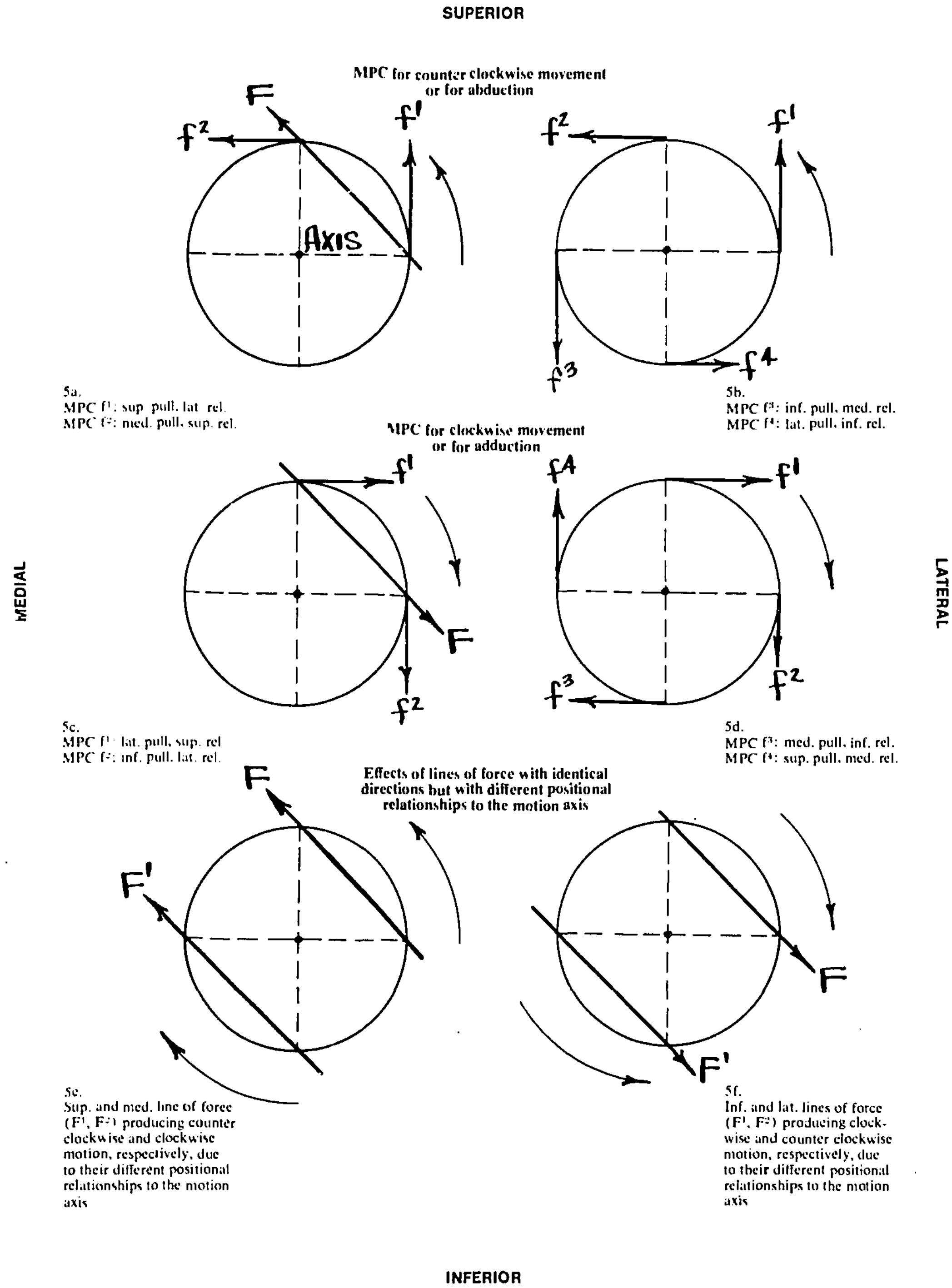


Figure sequence 5a–f. Identifying MPC in the frontal plane. The spatial orientation as shown is common to all diagrams and allows: a) for the determination of the directions of the lines of force, and b) for the determination of the positional relationships of the lines of force to the anterior-posterior motion axis, represented as a point within the wheel. In the body context, frontal plane movements are abduction and adduction.

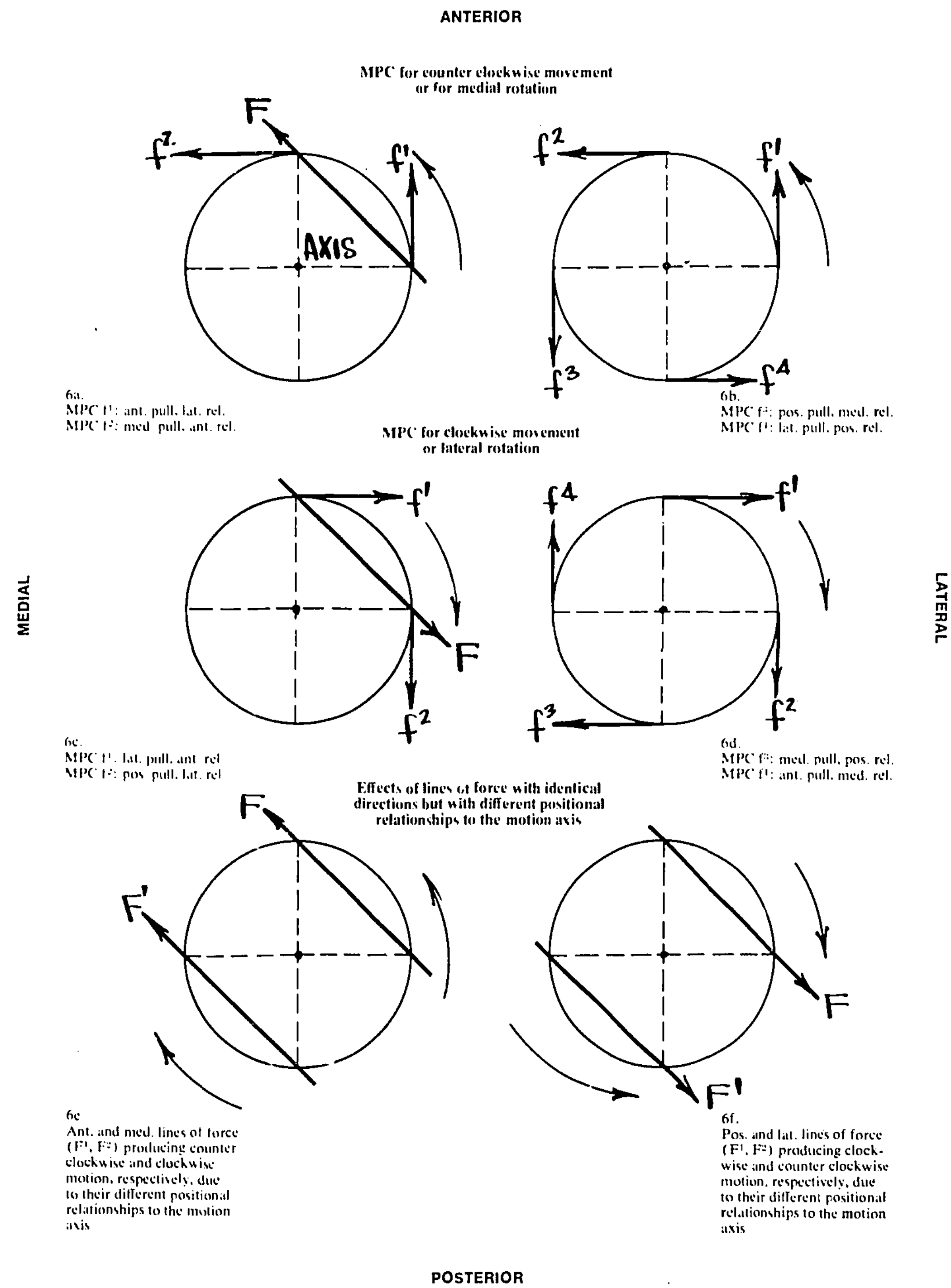


Figure sequence 6a–f. Identifying MPC in the transverse plane. The spatial orientation as shown is common to all diagrams and allows for the determination of: a) the directions of the lines of force, and b) the positional relationships of the lines of force to the longitudinal motion axis, represented as a point within the wheel. In the body context, transverse plane movements are medial and lateral rotation.

culty but they manage to some degree; they too seem to enjoy the confrontation with problem solving. Unfortunately, there are a few students who have exceptional difficulty with this approach. It appears that they are destined to approach the study of gross movement as produced by contracting muscles from the uninteresting, ineffective, and considerably less meaningful avenue of pure memory work.

In order to facilitate the development of the MPC concept it may be well to devise work experiences for students which challenge their understanding. A number of such homework experiences have been devised and are available upon request.

Suggested procedure for MAA

In the foregoing preparatory learning experiences for MAA, a mechanically oriented problem solving approach to the study of movements produced by contracting muscles was identified and briefly elaborated on. In the following, the procedure for MAA itself is described in detail. The procedure has four emphases, which consist of determining: a) the directions of pull (lines of force) of the muscle; b) the effective pulls of the muscle; c) the positional relationships of the muscle's pull to the axis of motion; and d) the movement producing combinations (MPCs). If the suggested procedure is adhered to, a minimum of difficulty should be encountered.

I. Determining the Directions of Pull (Lines of Force) of the Muscle

A. Locate the points of attachment of the muscle.

B. Decide what point of attachment is fixed and which is free. The free point is attached to the body segment undergoing movement; the fixed point is on the stabilized body segment. Ordinarily, the fixed attachment is proximal and the free attachment is distal in the extremities. When such is the case, the terms fixed and proximal, and free and distal are synonomous, or the reverse may be true.

(Note: The reversal of muscle action is discussed in section E.)

C. Determine the positional relationships of the fixed attachment to the free attachment by observing these points of attachment and the course of the muscle. For example, the fixed point of attachment may be superior or inferior, medial or lateral, and posterior or anterior to the free point of attachment.

D. The pulls of the muscle are determined on the basis of the positional relationships of the attachment points to each other. Since a contracting muscle may simultaneously pull in several directions toward its fixed point of attachment, a muscle whose fixed point of attachment is superior, medial, and posterior to its free point of attachment exerts its pulls or lines of force in those directions.

E. *Discussion.* With reference to the free and fixed points of attachment and, therefore, the lines of pull, the muscles themselves have no preference. In a shortening contraction, the muscle's disposition is to pull from each of its ends toward its center. It is the nervous system, fulfilling its integrative functions, that dictates to the muscles and establishes the free and fixed body segments and, thereby, the free and fixed points of attachment and the muscle's lines of pull. Under varying conditions the points of attachment and the lines of pull can be reversed . . . Whereas in one instance the muscle's fixed and free points of attachment may be proximal and distal, respectively (e.g., elbow flexors moving the forearm), under different conditions the fixed points of attachment may be distal and the free point may be proximal (e.g., elbow flexors moving the humerus) . . . In those instances where a muscle or its tendon courses so as to change its direction (pulley effect), one of the points of attachment is determined at that point where the pulley effect occurs . . . Once the directions of pull of the muscle are determined for a given condition (e.g., the anatomical position), they will apply at all times for that condition. Therefore, all of the muscle's pulls should be determined at the outset and noted.

II. Determining the Effective Pulls of the Muscle

A. The effective pulls of a muscle (line of force) are those which, by their action, produce angular motion. In order to produce angular motion the pulls of a muscle must act at a distance from the motion axis and in the plane in which motion occurs. Conversely, an ineffective pull would be one whose action does not produce angular motion about a given motion axis. Rather, its tendency would be to produce linear motion by acting in a direction parallel to the motion axis. In a three-dimensional system a muscle may have pulls which are superior or inferior, medial or lateral, and anterior or posterior. Two of the three pulls will be effective; one will not be. The chart below identifies the effective and ineffective pulls for each of the three fundamental motion axes.

Motion axis	Effective pulls	Ineffective pulls
transverse	a. superior or inferior b. anterior or posterior	medial or lateral
anterior-posterior	a. superior or inferior b. medial or lateral	anterior or posterior
longitudinal	a. anterior or posterior b. medial or lateral	superior or inferior

B. For a single joint, determine the axes of motion and movement planes permitted by the joint's structure. Use bony landmarks to indicate the approximate location of each axis on a specimen and on the living subject. Generally, the transverse and anterior-posterior axes of motion may be considered to pass through the center of the joint, while the longitudinal axis may be considered to pass lengthwise through the center of the bone. There are a number of exceptions to this statement but this basic approach generally will be satisfactory.

C. When determining the effective pulls, consider only one motion axis at a time.

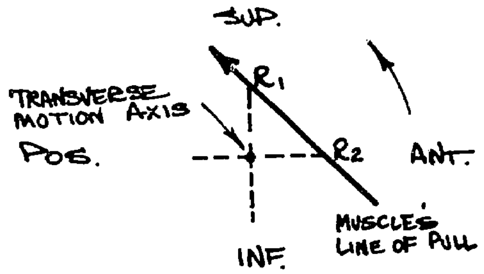
III. Determining the Positional Relationships of the Muscle's Pulls to the Motion Axis

A. Whenever possible, examine the muscle and the joint structure from a view which shows the axis under consideration in cross section, i.e., as a point.

B. The muscle's pull acts on the motion axis at the points where its line of direction crosses the motion axis. The positional relationships of the muscle's line of pull to the motion axis should be determined at these points, not where its attachments are. This is particularly necessary in those cases where the line of direction of the muscle's pull needs to be extended in order to cross the motion axis because the muscle does not actually cross the motion axis (e.g., the long head of the triceps around the transverse or anterior-posterior motion axes of the shoulder joint). Accordingly, the positional relationships of a muscle's line of pull to a given motion axis may be superior or inferior, medial or lateral, and anterior or posterior.

C. The positional relationships of the muscle to the motion axis may be determined schematically as follows: a) Examine the muscle-axis relationship as indicated in A. b) Intersect the point representing the motion axis at right angles with .wo broken lines. Extend the broken lines until they intersect with the line representing the muscle's line of pull (Figure 7a). It is at the points where the b oken lines intersect with the muscle's line of pull that the positional relationships of the line of pull to the motion axis are determined (R_1, R_2). Obviously, the naming of the positional relationships depends on the motion axis under consideration and the appropriate spatial orientation. To be consistent with the wheel and axle principle and to maintain sensitivity to angular motion, it may be well to proceed as above but to visualize the axis as a point within a wheel (Figure 7b).

D. If a muscle is so placed that an axis passes through it, the muscle needs to be considered as two or more units and should be analyzed accordingly (e.g., the deltoideus around all axes of the shoulder joint).



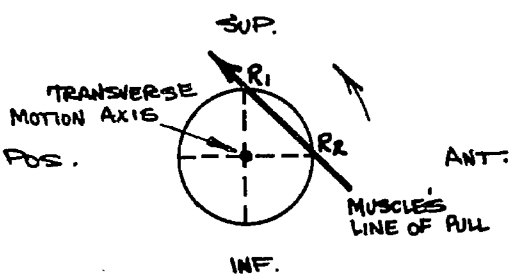


Figure 7a–b. Schematic determination of positional relationships (R_1, R_2) of a muscle's line of pull to a transverse motion axis.

Figure 8. The right posterior deltoid muscle and its line of pull from the anatomical position.

IV. Determining Movement Producing Combinations (MPCs)

A. For a given axis of motion, identify the two anatomical movements possible (e.g., flexion and extension about a transverse axis).

B. MPCs are a function of: a) the direction of the muscle's line of pull, and b) the positional relationships of the muscle's line of pull to the motion axis under consideration. Generally, the muscle's line of pull will have two components and two positional relationships to the motion axis. When such is the case, the proper matching of pulls and relationships will result in two MPCs for each movement (refer to Figure sequences 4–6).

MAA illustrated

Figure sequences 4–6 have used the wheel and axle principle to illustrate the MPC concept. In this context the MPC concept is readily understood by most students. The problem for the student arises when the attempt is made to transfer these understandings to the body context. While the instructor may help, it is the student himself who has to understand. To illustrate the MAA procedure in the body context, the posterior deltoid muscle has been selected for analysis (Figure 8). This muscle acts on the triaxial shoulder joint to produce movement in each of the three fundamental body planes. The deductive analysis is shown on an MAA worksheet (Figure 9) used by students to facilitate their efforts and for easy checking by the instructor. Repeated experiences of this type will lead the way toward mastery of MAA.

It should be noted that the MPCs as shown emanate from the anatomical position. As a segment moves through its range of motion, the line of pull of the involved muscle and its positional relationships to

MUSCLE ACTION ANALYSIS (MAA) WORKSHEET

Joint	Functional Classification	Muscle (M)	M. Proximal Attachment	M. Distal Attachment	M. Directions of Force (3)
Shoulder (gleno humeral)	Triaxial	Posterior deltoid	Lower border of scapular spine	Deltoid tuberosity	Superior (sup.) Medial (med.) Posterior (pos.)

MOVEMENT PRODUCING COMBINATIONS (MPC's)

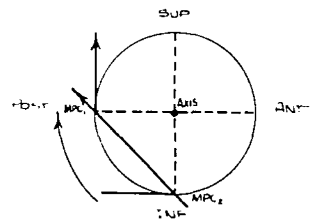
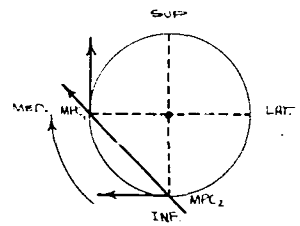
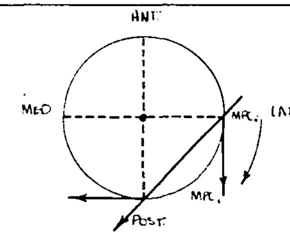
Anatomical Movement	Motion Axis		Effective Lines of force (2)	and	M. Positional Relationships to Motion Axis (2)	Proof Diagrams
1. Extension	Transverse (Transverse-Frontal)	MPC-1: MPC-2:	sup. pos.	and and	pos. inf.	
2. *Adduction*	*Anterior-*Posterior (Sagittal-Transverse)	MPC-1: MPC-2:	sup. med.	and and	med. inf.	
3. Lateral Rotation	Longitudinal (Frontal-Sagittal)	MPC-1: MPC-2:	med. pos.	and and	pos. lat.	

Figure 9. MAA worksheet illustrating analysis of the right posterior deltoid muscle.

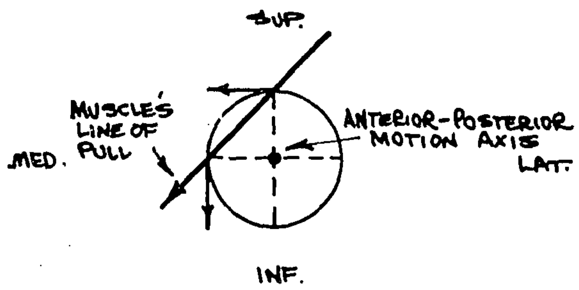


Figure 10. Proof diagram for the right posterior deltoid muscle assisting in abduction when the humerus approximates 180° abduction.

the motion axis change; therefore the movement produced by the muscle, mechanically speaking, is a function of different MPCs. In Figure 10 the line of pull of the posterior deltoid is shown schematically in a proof diagram when the humerus approximates 180° abduction. In this position it is likely that this muscle, ordinarily a strong abductor, assists other muscles in the abduction movement because of the shift in its line of pull and positional relationships to the anterior-posterior motion axis.

Concluding remarks

This paper has been written to explain a method of analyzing the action of contracting muscles from a mechanical standpoint. Experience supports the view that MAA is replete with the elements of problem solving. It can be, therefore, a potentially challenging, stimulating, productive, and satisfying way of studying muscle action.

It is recognized that muscle action is a multidimensional phenomenon and that there are limitations in viewing movements produced by contracting muscles in a purely mechanical sense. Results from electromyographic studies, for example, tell us that muscle action is not simple. It must be pointed out, however, that if a muscle is to produce a movement, mechanically speaking, it must first be in position to do so; whether it does or not depends upon environmental conditions and the integrative action of the nervous system.

T. L. DOOLITTLE

Errors in Linear Measurement with Cinematographical Analysis

IT HAS BEEN OVER 30 YEARS since Cureton (1) set forth elementary principles for the use of cinematographical methods in analyzing human performance. These were in essence reiterated by Glassow (2) and Hubbard (3), and numerous studies in physical education have used them; however, there has been a paucity of literature in the discipline regarding any improvement in or critical analysis of these methods. Noss (4), a noted exception, published his work regarding the inherent errors in angular measurements. Techniques for the reduction of errors in linear measurements have not been elucidated. Since the utilization of cinematographical methods for analysis of complex or high speed human movements is becoming increasingly popular, it appeared that there was a great need for establishing more accurate techniques for reducing these linear errors.

The assessment of linear distance from film frequently is a primary parameter either for distance *per se* or for the ultimate determination of velocity. This method is subject to errors that the naive investigator may fail to take into account, even though he is following what is generally thought to be accepted practice. Perspective errors result when three-dimensional objects are reduced to two dimensions on the film, with those nearer appearing larger than those that are more distant. Increasing the camera-to-subject distance, while partially reducing this source of error, does not completely eliminate it, nor is this recommendation always practical. Utilization of a grid for a background creates perspective errors for which corrections should be made. A second source of error — scaling errors — may result when the projected image is other than actual (life) size. An object of known size is usually included in the field of view, measured on the projected image, and a scale factor derived to convert measured values (in inches, millimeters, etc.) to the desired values (in feet, meters, etc.). The accuracy of the scale factor obviously influences the accuracy of the ultimate determination. The significance of this potential source of error, often overlooked, will become quite apparent later in this report.

The placement of the object of known dimension in the plane of action will reduce perspective errors, but unless it is of large size scaling errors will be enhanced. Regardless of its size, the object may impede the desired action, requiring its placement parallel to the plane of action. This is the situation that exists when a grid is used for a background. Figure 1 illustrates the physical arrangement of a camera, a distance of hypothetical action (r), and a grid. On the two-dimensional image of a photograph *r*

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will appear as n.* This may be observed in Figure 2 where the hurdles appear to be superimposed on the grids. The effect of altering d and/or s (Figure 1) also may be observed in these photographs. The purpose of this study was to evaluate the relative effects of perspective and scaling errors, and to investigate techniques for eliminating them.

Procedure

Frame by frame analysis, such as might be employed in determining the distance between two points for subsequent computation of velocity, was simulated in each of eight still photographs. In actual analysis these two points would undoubtedly occur in different frames; however, for purposes of this study having them in the same frame permitted standardization without detracting from the basic technique. Hurdles, in a plane perpendicular to the axis of the camera, were utilized to represent the points. The distance (r) between the right vertical bars on the right and middle hurdles (Figure 2) was held constant at 12.5 feet throughout the investigation. The axis of the camera was maintained perpendicular to the plane of the grids at the center of the middle grid. The values for d and s (Figure 1) were varied as indicated in Table 1. Frames 1, 2 and 3, and 4 and 5 were originally photographed for purposes of testing different exposures, but ultimately were utilized to determine intra-operator error. Frames 1, 5, 7, and 8 are exemplified by Figure 2, A, B, C, and D, respectively. Three operators independently analyzed the film using a Kodak Recordak Model MPE-1.

Perspective Errors

The first subproblem in this investigation was to determine the magnitude of perspec-

* In keeping with the terminology and symbols used subsequently in this report, it should be noted that r and n are life size; thus, in reality, on the projected image one is oberving m which when multiplied by the scale factor (k) becomes n ($n = km$).

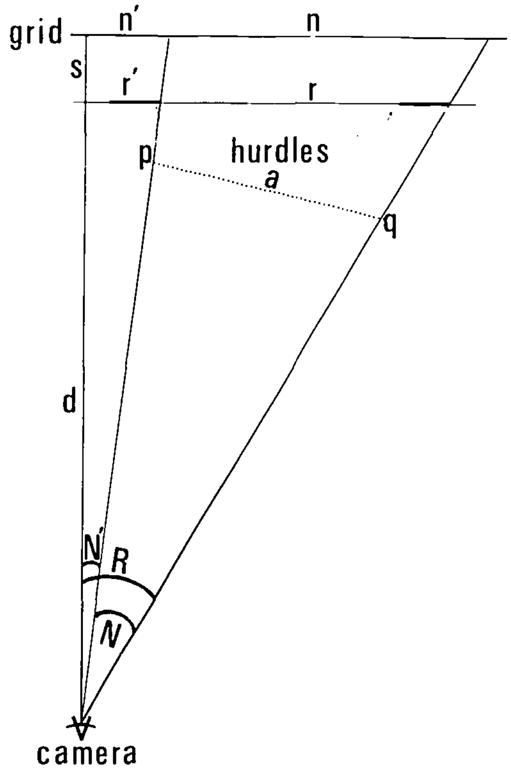

Figure 1. Diagram of camera, grid, and hurdle placement, showing various variables.

d — distance from camera to plane of hurdles (i.e., simulated plane of action); line also represents axis of camera lens.

s — distance hurdles were in front of reference grid.

r — actual distance between points being measured.

n — uncorrected value of r measured from the projected image from the film as m (in mm) and converted to feet by the scaling factor **k** (see text).

r' — distance one of the points was offset from the center of the image.

n' — apparent value of r', measured from the film (as with n)

a — distance between two hypothetical points **p** and **q** that is not parallel to the grid. (Note also, that a projects the same m, thus the same **n**, as r unless precautions and/or corrections are taken into consideration).

N — angle opposite side n; also opposite side **r**; equals angle **R** minus angle **N'**.

N' — angle opposite side n'; also opposite side r'; tangent **N'** equals n'/(s+**d**) or r'/d.

R — angle opposite side n+n', also opposite r+r'; tangent **R** equals (n+n')/(d+s), or (r+r')/d.

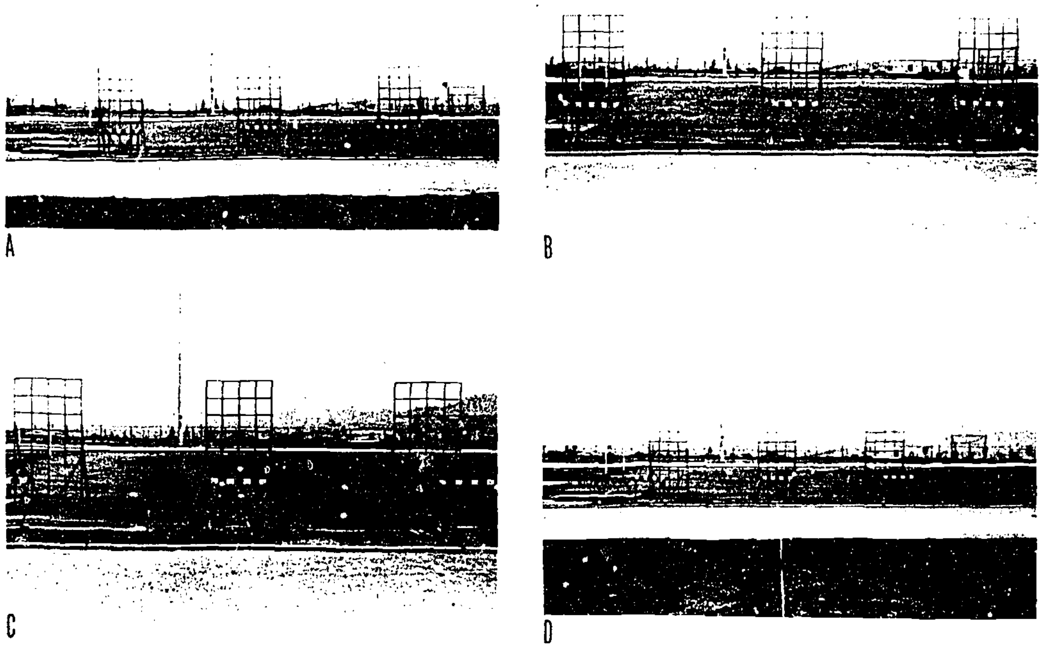

Figure 2. Four views of grid and hurdle placement. Distance (r) between right vertical bars of right and middle hurdles was 12.5 ft. in all exposures. Camera to hurdle plane (d) and hurdle plane to grid plane (s) distances were varied as follows: (A) d = 80 ft., s = 4 ft.; (B) d = 56 ft., s = 4 ft.; (C) d = 46 ft., s = 9 ft.; and (D) d = 96 ft., s = 9 ft. Grids were made of squares 1 ft. on a side and were placed: 13'2" on center for views A and B; and, 11'7" on center in views C and D.

TABLE 1. VARIABLE VALUES FOR THE EIGHT PHOTOGRAPHS

Frame	d (ft.)	s (ft.)	$\frac{d}{d+s}$
1,2,3	80	4	.95238
4,5	56	4	.93333
6	46	4	.92000
7	46	9	.83636
8	96	9	.91429

d & s are as indicated in Figure 1.

tive errors and explore techniques for their reduction. A scale factor (k) was determined for each frame by noting the number of millimeters on the graph paper that were equivalent to one foot on the projected image of the grid. The distance between the two points (the right vertical bars of the two hurdles) was measured in millimeters (m). The scale factor was used to convert m in millimeters to n in feet ($n = km$). Formula (1)

$$\% \text{ Error} = \frac{n - r}{r} \times 100 = \frac{n - 12.5}{12.5} \times 100 \quad (1)$$

was utilized to determine the percentage of error in n (with respect to the actual distance of 12.5 feet) prior to correction. Formula (2)

$$l = \frac{d}{d + s} \times n \quad (2)$$

was employed to correct n for perspective error and resulted in the calculated value, l. If no other errors were involved l would equal r, or 12.5 feet. The percent error in the calculated l was determined by substituting l for n in Formula (1). Table 2 de-

TABLE 2. OBTAINED (n) AND CORRECTED (l) VALUES FOR THE ACTUAL DISTANCE (r) WITH PERCENTAGE ERROR FROM 12.5 FEET IMMEDIATELY BELOW EACH VALUE

FRAME		OPERATOR A n	OPERATOR A l	OPERATOR B n	OPERATOR B l	OPERATOR C n	OPERATOR C l
1	ft.	13.45	12.81	13.17	12.54	13.73	13.08
	%	7.60	2.48	5.36	0.32	9.84	4.64
2	ft.	13.35	12.71	13.17	12.54	13.73	13.08
	%	6.80	1.68	5.36	0.32	9.84	4.64
3	ft.	13.30	12.67	13.17	12.54	13.73	13.08
	%	6.40	1.36	5.36	0.32	9.84	4.64
4	ft.	13.21	12.33	13.53	12.63	12.82	11.97
	%	5.68	−1.36	8.24	1.04	2.56	−4.24[a]
5	ft.	13.20	12.32	13.56	12.66	12.86	12.00
	%	5.60	−1.44	8.48	1.28	2.88	−4.00[a]
6	ft.	13.36	12.29	13.41	12.34	12.76	11.74
	%	6.88	−1.68	7.28	−1.28	2.08	−6.08[a]
7	ft.	14.72	12.31	14.64	12.25	14.22	11.89
	%	17.76	−1.52	17.12	−2.00	13.76	−4.88
8	ft.	13.95	12.75	13.38	12.23	13.43	12.29
	%	11.60	2.00	7.04	−2.16	7.44	−1.68

[a] Denotes increase in magnitude of the error with correction applied. Minus sign denotes corrected value was less than 12.5 ft. and solely indicates the direction of the error.

picts the measurements m after they had been converted to n and corrected to l, and the respective errors, obtained by the three operators for each frame. In Frame 1, for example, Operator A determined that the distance was 13.45 feet, based on measuring the projected image (m) and converting to feet (n) with his scale factor (k); this resulted in an error of 7.60 percent; employment of Formula 2 resulted in an l of 12.81 and a remaining error of 2.48 percent. It should be noted from the values for Frames 7 and 8 that increasing the distance(s) between the grid and the plane of the action greatly increased the error in the uncorrected value n. Increase of the camera-to-action distance (d), from 46 feet in Frame 7 to 96 feet in Frame 8 compensated for the error in part, but not to the degree that Formula (2) did, as may be noted from the respective values for l.

Scaling Errors

The second subproblem, investigation of scaling errors, developed when it was observed that considerable residual error remained in many cases after n had been corrected to l. The negative percentages for errors in l implied overcompensation, or that the value of m was too small. The positive percentage implied undercorrection, or that m was too large. This variance of results, combined with the fact that for given values of d and s the multiplier of n, $d/(d + s)$, in Formula 2 remains constant, dictated that the source of the error was in n and that it could not have been in the degree of correction. There were two probable sources for error in n: (1) measurement of the image m (in millimeters), and/or (2) inaccuracy in establishing scale factor. Analysis of two of the operators' raw data revealed that they

had identical measured values for Frames 6 and 7, and varied only .5 mm on the image measurement for Frames 1, 2, 3, and 8; the scale factors, however, varied by greater percentages (Table 3). A comparison of the differences between operators, from the data in Table 2 with the percent variations in Table 3, made it rather apparent that the primary source of interoperator error was in the scaling factor.

Assuming agreement between operators demonstrated a reasonable degree of accuracy, Frames 6 and 7 were utilized to develop a theoretical scale factor. This was determined by calculating the actual *n* that would be subtended on the grid by *r* and dividing the measured image *m* by it. The resultant theoretical scale factor for the two frames in which there was absolute agreement and the operators' scale factors are

TABLE 3. COMPARISON OF RAW DATA AND SCALE FACTORS BETWEEN TWO OPERATORS

	Measurements from Projected Image (mm)			Scale Factor (mm/ft) Determined from Projected Image		
Frame	B	C	% Var.	B	C	% Var.
1	151.5	151	.33	11.5	11.0	4.35
2	151.5	151	.33	11.5	11.0	4.35
3	151.5	151	.33	11.5	11.0	4.35
4	216.5	218	.07	16.0	17.0	5.88
5	217	218.5	.07	16.0	17.0	5.88
6	261.5	261.5	0	19.5	20.5	4.88
7	263.5	263.5	0	18.0	18.5	2.70
8	140.5	141	.35	10.5	10.5	0

TABLE 4. COMPARISON OF THEORETICAL AND EMPLOYED SCALE FACTORS

Frame	Actual[a] n (ft)	Image m (mm)	Theor. Scale	B's Scale	%[b] Error	C's Scale	%[b] Error
6	13.59	261.5	19.25	19.5	1.30	20.5	6.49
7	14.95	263.5	17.63	18.0	2.10	18.5	4.93

[a] Actual distance on grid subtended by *r* (See Figure 1).

[b] Denotes operator's error in percent with respect to the theoretical scale (i.e., operator C's scale for Frame 7 was 4.93% in error).

TABLE 5. ACTUAL VERSUS THEORETICAL ERRORS[a] (all values in percent)

	Operator B			Operator C		
Frame	Actual	Theor.	Diff.	Actual	Theor.	Diff.
6	1.28	1.30	.02	6.08	6.49	.41
7	2.00	2.10	.10	4.88	4.93	.07

[a] Actual errors are the percent *l* was in error with respect to *r* (Table 2); theoretical errors are the percent the operator's scale factor was in error from the theoretical scale factor.

contained in Table 4. A comparison of the theoretical errors in scaling from Table 4 with the actual errors for l in Table 2 resulted in residual error differences that were negligible (Table 5). This demonstrated that errors in scaling could account for remaining error after correction for perspective error had been made.

Findings

The findings of this investigation were summarized as follows:

1. Formula (2) was found to correct adequately for perspective errors regardless of the magnitude of d and s.
2. Accuracy in the establishment of the scale factor was highly important; errors in scaling can overshadow any benefit derived from correction for perspective error.
3. Accuracy in measurement of the projected image was of lesser importance than either of the above, and discrepancies herein were not significant.
4. Intra-operator error between duplicate frames was minimal.

Discussion

The traditional recommendations for cinematographical analysis have indicated that the linear reference for determining the scale factor should be in the plane of the action. The potential hindrance of such placement has already been noted. In addition, even in a straight run it is extremely difficult to maintain the performer in a constant plane. Utilization of a grid solves these problems in part but does enhance perspective errors. Formula (2) corrects for the perspective errors and potentially allows for the inconsistency of the performer by permitting d and s to vary by known amounts. If a grid is utilized as a background, and if the scale factor is initially determined from an actual n calculated from known d, s, and r values, then as long as $d + s$ remains constant the scale factor (k) will remain constant. This will permit the above mentioned variation of d or s, and make possible the correct determination of subsequent unknown values of l by appropriately modifying the multiplier, $d/(d + s)$. For example, the original scale factor could be determined for the middle of the long jump runway (proposed plane of action), and correct values for l determined if the jumper were off to one side, as long as the deviation from the center were known so that d could be modified. The scale factor would not change as that relates to the grid, but the multiplier would be modified to correct n for the offset. Knowledge of the offset could be obtained by having a series of parallel lines, of known distances apart, perpendicular to the axis of the camera. Two precautions should be noted: a) the scale factor should be determined over the greatest lineal dimension possible in order to minimize any error in its determination, and b) in order for the scale factor to remain constant, as indicated above, the sum of d and s must remain constant (i.e., if one increases the other must decrease by the same amount, or putting it another way, the distance between camera and grid must remain constant). In addition to improving the accuracy of linear measurements in cinematographical analysis, these techniques will permit filming at closer range where insufficient space prevents the use of the often recommended telephoto lens.

The units of kinetic energy as shown in be perpendicular to the camera axis has been virtually inviolable. This practice was followed throughout the present investigation. The basic logic for such doctrine may be observed in Figure 1, where it should be noted that a would produce the same n as would r. From the practical standpoint, the concept of perpendicularity undoubtedly should be followed; however, it is theoretically possible to ascertain the correct value for a if the procedure described below is employed. The distances that points p and q are from the camera must be known — this might be accomplished with the aforementioned series of parallel lines or with concentric arcs of known distances in the field of view. Formula (3), an application of the Law of Cosines, where b and c are the distances p and q are from the camera, permits solving for a:

$$a^2 = b^2 + c^2 - 2bc(\cos N) \qquad (3)$$

The cosine of angle N may be obtained from trigonometry tables, since the following relationships hold true:

$$\tan N = \tan R - \tan N' = \frac{n + n'}{d + s} - \frac{n'}{d + s} = \frac{n}{d + s}$$

The value for d + s will be the constant distance between the camera and the grid. The value for *n* will be *km*, where *k* (the scale factor) has been determined as described above and *m* is the projected image value for *a*. The significant difference between this approach and the one verified in this investigation is that after obtaining *n*, instead of applying the multiplier, d/(d + s), one divides by (d + s) to obtain the tangent of N, and then knowing *b* and *c* utilizes formula (3). The increase in complexity of this procedure should not be minimized, but it could be effectively employed.

References

1. Cureton, Thomas K., Jr. Elementary principles and techniques of cinematographic analysis as aids in athletic research. *Research Quarterly* 10:3-24, May 1939.
2. Glassow, Ruth. Photographical and cinematographical research methods. *Research methods applied to health, physical education, and recreation* (rev. ed.). Washington, D.C.: American Association for Health, Physical Education, and Recreation. 1952. Chapter 9, pp. 204-218.
3. Hubbard, Alfred W. Photography. *Research methods in health, physical education, and recreation* (2nd ed.). Washington, D.C.: American Association for Health, Physical Education, and Recreation, 1959, pp. 128-47.
4. Noss, Jerome. Control of photographic perspective in motion analysis. *Journal of Health, Physical Education, Recreation* 38:81-84, September 1967.

M. MARILYN FLINT

A Differential Study of the Hip Extensor Muscles

THE GLUTEUS MAXIMUS and the three hamstring muscles, the semimembranosus, semitendinosus, and biceps femoris, are generally ascribed the function of thigh extension at the hip joint. How much effort each contributes to the total movement of hip extension and the phase during which each is working has not been determined. There is some disagreement in the literature as to the extent of involvement of the gluteus maximus and the hamstrings in other prime mover actions such as adduction, abduction, lateral and medial rotation.

It is a generally accepted fact that muscles may perform differently during activity than when performing prime mover activity in a clinical situation. Basmajian (1), Close (2), Eberhart (3) and Inman (6) and other kinesiologists have found that muscles do not act strictly as agonists nor antagonists but rather that they work in groups and contract in a coordinated, associated, orderly manner. Wheatley and Jahnke (12) determined the functions of hip and thigh muscles with the thigh held in various positions and found that postural differences do affect the extent of activity of muscles during movement.

The extent of effort made by the gluteus maximus during the performance of a few selected activities has been investigated electromyographically. One could expect that a muscle with such a large cross-sectional area would have a major responsibility in the performance of fundamental movements. Yet the evidence reveals that the gluteus maximus has a relatively minor role in daily routine movements. This may explain why it is one of the first muscles to lose its firmness and tone. The activities which have been selected for measuring the muscle potential activity of the gluteus maximus and other lower extremity muscles include walking, riding a bicycle, and balance movements such as maintaining and assuming an upright posture. How much the gluteus maximus contributes to the performance of other exercises and activities is questionable.

The purpose of this study was a) to compare the functions of the gluteus maximus, the semitendinosus, and the biceps femoris during a wide variety of prescribed movements and b) to determine the activities in which the gluteus maximus was most active.

METHOD AND PROCEDURE

Equipment

A Meditron* electromyograph, Model 302, was used to record the data for this study. This instrument was equipped with a dual channel cathode ray oscilloscope which made it possible to record simultaneously the potential activity of two separate muscles.

A Bolex 16 mm reflex camera equipped with an optical beam-splitting device was situated in such a way as to simultaneously record the traces on the oscilloscope, the

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* Appreciation is extended to the Meditron Co., A Division of Crescent Engineering and Research Co., 5440 North Peck Road, El Monte, California, for use of their machine.

data board mounted above the oscilloscope, and the subject. An exact reading of the subject's movements and the corresponding muscle responses was thus obtained on a permanent record. The physical arrangement of the instruments and apparatus are described in detail in a previous article by the author (4).

Monopolar needle electrodes used to pick up the action potentials were placed approximately in the center of the muscle belly of each of the muscles under observation: the gluteus maximus, semitendinosus, and long head of the biceps femoris. The semimembranosus was not selected for study because of its inaccessibility. It is to a large extent covered by the semitendinosus and by the adductor magnus, making an accurate placement of the electrodes difficult.

The sensitivity of the electromyograph was set at 1,000 microvolts per centimeter for both channels and the sweep speed was set at 20 milliseconds per centimeter. The machine was adjusted for each muscle of every subject, using a contraction against every heavy resistance to adjust the amplitude to 2 cm of vertical deflection.

In order to confirm the accurate placement of the electrodes, the subject performed a maximum contraction of each muscle against resistance, the gluteus maximus in hip extension and the hamstrings in knee flexion. Inspection, palpation and electrical activity determined whether the correct site had been obtained. The pattern of these potential readings also served as an index for a very strong contraction when the recordings were analyzed.

Movement

Seven University of California students, five women and two men, served as subjects. They were instructed to perform only the selected exercises listed below. No recordings were made until the exercise was performed correctly. All subjects performed the same movement in an identical, or as nearly identical manner as possible. Exercises which were considered more difficult were practiced prior to the recording session. The movements were not recorded until the subject had relaxed to the point where electromyographic silence was obtained on the oscilloscope.

In some exercises moderate resistance was applied throughout the total range of movement in order to place a greater work load on the muscles being used. In the exercises requiring the support of both the body and the left leg, two tables were employed. One table supported the body and the second table, parallel and adjoining the first at one corner, supported the left leg in such a manner as to allow the right leg free range of movements.

Movements were performed in a wide variety of positions and in every possible direction about the axis of joint rotation in order to learn, as nearly as possible, the total function of the muscles. Because only a dual channel instrument was used, the subjects performed one complete series of exercises testing the gluteus maximus and semitendinosus. The series was then repeated to test the biceps femoris and gluteus maximus. Muscle fatigue did not appear to be a factor. The subjects were very well conditioned and the exercises did not require great effort. However, rest between the exercise series and between the exercises was used.

The Basic Exercises

1. *Extension of the thigh at the hip joint.* The body and left leg were supported in the prone position on tables, the right thigh flexed to approximately 60° with the right foot touching the floor, knee extended. The subject extended the right thigh from 60° flexion to approximately 45° hyperextension and then slowly returned to the initial position.

This same exercise was executed while keeping the knee flexed, and performed with and without resistance which was applied manually at the knee throughout the total range of movement.

2. *Extension of thigh against wall pulley.* While standing facing a wall pulley, the thigh was extended. A leather cuff attached to the pulley rope encircled the lower part of thigh.

3. *Abduction of the thigh.* The subject was in a left side-lying position, with the legs together, knee extended and thigh in a neutral extended position. The leg was then abducted

at the hip, from 0° to approximately 30° and returned to the initial position. Resistance was applied manually at the knee throughout the entire movement.

The exercise was repeated with the thigh flexed and again with thigh held in hyperextension.

4. *Adduction of the thigh.* The subject was in a left side-lying position with the right thigh abducted with the knee extended. The right thigh was then adducted from 30° to 0°, or until it touched the left thigh. Resistance was applied manually at the knee throughout the entire movement. This movement was repeated with the thigh held in a flexed position and again when the thigh was in hyperextension.

5. *Abduction and adduction of the thigh in a standing position.* (An isometric contraction.) The subject stood with the weight of the body on the outside borders of the feet. He then forcibly tried to adduct the legs by attempting to pull his feet together against the coercion of the floor. After several attempts he then attempted to draw his feet outward in abduction.

6. *Isometric contraction of gluteus maximus and hamstrings.* Lying in a prone position, the subject tightened as firmly as possible the gluteus maximus and hamstring muscles and held for 10 seconds.

7. *Lateral and medial rotation of the thigh.* The body and the left leg were supported in a position by tables, with the right leg, knee extended, supported in the neutral position by an assistant. Resistance was applied manually at the knee against lateral and medial rotation.

8. *Treadmill.* Walking was performed on the level, and on a 30° incline. The subject walked on a portable treadmill* which was activated by the walking of the subject. A waist-high hand grip was used for stability. Treadmill running was performed only on the level.

9. *Vertical jump.* The subject performed one maximum vertical jump for height utilizing full extension of the body.

10. *Low bench stepping.* Ten-inch and 17-inch benches were used. The subject stepped up on a bench with the right foot, extended to a standing position, and then stepped off the bench with the left foot, while the right foot supported the weight of the body.

11. *Bicycle riding.* The subject rode a stationary bicycle while in a sitting position. The thigh moved from 60° flexion at the top of the power phase, to −15° of hyperextension at the conclusion of the power phase.

12. *Pelvic tilt.* Rotating the pelvis up and back (posterior tilting) until the small of the back touched the table.

13. *Toe touching.* From the standing position with knees in easy extension, the subject leaned forward to touch his toes with his hands, and then returned to the normal standing position.

14. *Body sway.* The subject maintained good body alignment and swayed forward from the ankles until he nearly lost his balance.

Treatment of data

The cinematographic recordings were analyzed on a 16 mm Kodoscope Analyst projector modified for stop and interval readings, and a Recordak microfilm reader. Amplitude and frequency of the action potential response were the parameters used for measuring the magnitude of muscle activity. The electrical activity was then rated according to zero, trace, mild, moderate, and strong for each phase or division of the exercise or activity performed by the subjects. Arbitrary number values were awarded each of the categories: 0 for zero reading; 10 for trace; 20 for mild; 30 for moderate; 40 for strong. The exercise was analyzed in degrees if the movement took place around an axis of rotation as in hip extension. Each phase of extension, for example, consisted of 15° of movement. If the movement was sustained as an isometric contraction or a linear movement such as a vertical jump, the action was broken into logical segments or phases such as tighten-release, or up-down.

Mean readings were obtained for each muscle for each phase of the exercise and graphed for analysis. Subsequently, a grand mean was made from those means to determine an average potentional reading for each muscle in each exercise. The results of this procedure were also graphed. Although an average was established for the amount of involvement each muscle had in the total exercise, a true picture of muscle activity was not shown on this composite.

* Hamlin Health Hiker. Hamlin Products, 2741 Wingate Avenue, Akron, Ohio 44314.

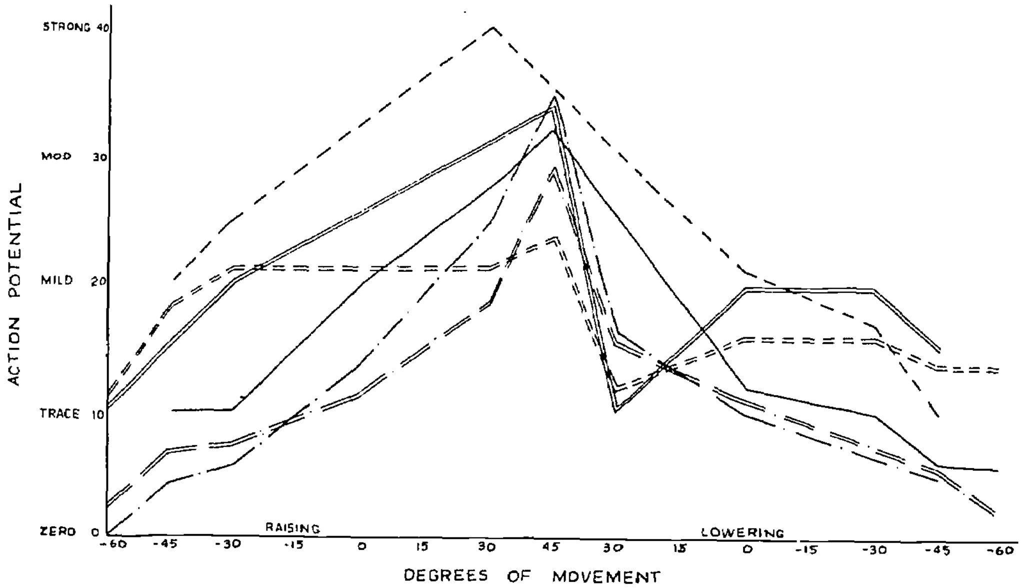

Figure 1. Mean readings in extension, knee extended. *Biceps femoris* ———; *Gluteus maximus* — . —; *Semitendinosus* — — —

Mean readings in extension, knee flexed. *Biceps femoris* ═══; *Gluteus maximum* = : =; *Semitendinosus* = = =

Negative degrees on extreme right and left of graph indicate leg is in flexion; 0 degrees, leg is in neutral position; positive degrees, leg is in hypertension.

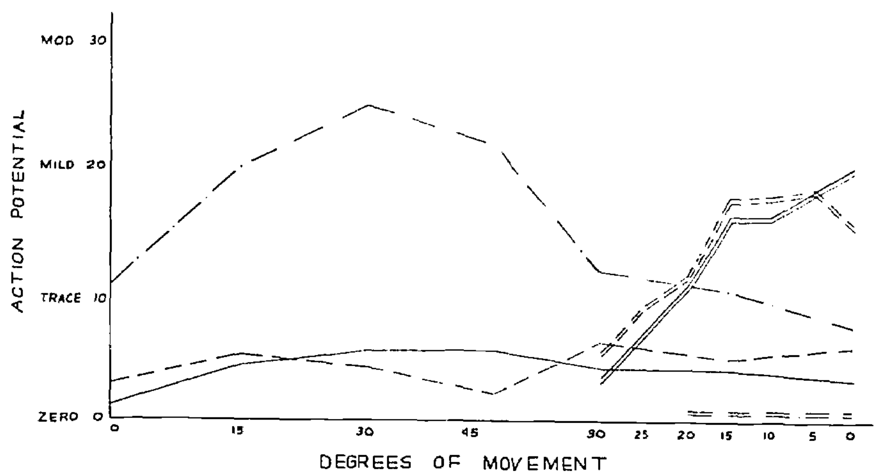

Figure 2. Mean readings in abduction, 0° - 45°. *Biceps femoris* ———; *Gluteus maximus* — . —; *Semitendinosus* — — —

Mean readings in adduction, 0° - 45°. Return of leg from abducted position against resistance. *Biceps femoris* ═══; *Gluteus maximus* = : =; *Semitendinosus* = = =

ANALYSIS OF THE DATA AND DISCUSSION

Extension exercises* (Figure 1)

The potential recordings for the three muscles investigated followed a similar graphical pattern through the total range of extension from 60° flexion through the 0 or neutral position to 45° hyperextension. The potential activity for each of the muscles gradually increased from a low intensity at 60° flexion to a strong intensity at 45° hyperextension. A reverse pattern was evident on the lowering or final phase of the exercises.

The hamstring muscles begin and control backward extension when the movement is initiated with the thigh in a flexed position. Not until the hip was in 5° to 10° hyperextension did the gluteus maximus show involvement, which gradually increased to a moderate reading at 30° and a very strong reading at 40°. Hyperextension beyond approximately 10° is known to take place in the lumbar articulations. The high potential activity is very possibly the result of strong action of the extensors to overcome the resistance of antagonistic structures on the anterior side of the hip. Levine and Kabat (9) observed a similar response from the anterior deltoid in arm elevation. In agreement with other studies (1, 12), the gluteus maximus was found to be most effective as a hip extensor when the muscle worked against heavy or moderate resistance. A one-lift maximum and extension against a heavy weight by use of a wall pulley involved the gluteus maximus earlier in the cycle of extension.

As stated earlier, the pattern of muscle activity in prime mover activity may be different than when performing a like movement in coordinated activities. This becomes quite apparent when comparing walking with the controlled exercise of extending the leg through its full range of movement. In walking the gluteus maximus contracts at contact when the leg is in forward flexion. Whereas, as shown in this series of extension exercises, it does not work to any extent until the leg is in hyperextension.

Whether the hamstrings work best at the hip if the knee is held in extension or flexion has frequently been questioned. Wells (11), for example, believes that "the effectiveness of the biceps femoris as an extensor of the hip is in reverse proportion to the degree of flexion at the knee joint." Markee and associates (10), in explaining the activity of two-joint muscles of the thigh, utilize morphology in addition to the theory of dissipation of tension within the amplitude of muscle contraction as Wells has done. They have classified the semitendinosus as a digastric muscle due to an intervening tendonous inscription. Consequently, the muscle can work at one end without involving the other end, or as a "powerful hip extensor irrespective of whether the knee is flexed or extended." Basmajian (1, p. 68) in electromyography studies, was unable to substantiate the thesis presented by Markee and has shown that a two-joint muscle operates simultaneously in both joints. In attempting to determine the function of the hamstrings at the hip joint, measurements were taken with the knee both in passive flexion and in extension.

A comparison of the electromyograms between hip extension movements when the knee was flexed and when it was extended revealed only a slightly variable graphical picture. The semitendinosus did record slightly stronger potential activity when the knee was held in extension. The biceps femoris recorded slightly stronger potentials when the knee was in flexion. However, since the difference was minimal, the readings of all extension exercises were combined and recorded in one graph.

Abduction exercises (Figure 2)

The gluteus maximus recorded potential activity during abduction whether the thigh was is a position of flexion, extension or hyperextension. This is in disagreement with others. Gray, in his *Anatomy*, does not include it as an abductor of the hip. Other anatomists claim that only the anterior or

* A brief analysis of extension has been shown in a previous article (4).

upper fibers contribute abduction. Wheatley and Jahnke found it to abduct against heavy resistance when flexed at approximately 60°. Inman (6) determined that the position of the gluteus maximus in relation to the hip joint limited its capacity to serve as a hip abductor. Neither of the hamstring muscles contributed appreciably to the movement of abduction.

Adduction exercises (Figure 2)

The gluteus maximus recorded no electrical activity during adduction. Wheatley and Jahnke found some activity in the gluteus maximus when the thigh was held in an abducted position and worked against heavy resistance. During forceful movements of adduction, the potential readings for both the biceps femoris and the semitendinosus ranged between trace and mild.

Lateral and medial rotation exercises (Figure 3)

Whether the thigh was held in extension, flexion, or hyperextension, the biceps femoris was found to be a strong lateral rotator and the semitendinosus a strong medial rotator.

The gluteus maximus readings on two of the subjects were of mild intensity during lateral rotation. Five subjects, however, did not record electrical activity. The gluteus maximus recorded no electrical activity during medial rotation of the thigh for any of the subjects.

Isometric contraction (Figure 4)

Tightening and holding the gluteus maximus and hamstring muscle recorded moderate to very strong readings for the gluteus maximus whether the subject was in the prone, supine, or sitting position. The hamstring recordings during this exercise showed considerable variation between subjects. This was possibly due to the difficulty in isolating the hamstrings for an isometric contraction.

Pelvic tilt (Figure 3)

The pelvic tilt can be performed without activating the hip extensors although the mean recordings show trace plus activity. The amount of effort the subject put into holding the position determined the potential activity of the muscles. (Two subjects recorded moderate to strong. Two were trace, plus, and two were zero.)

Treadmill walking and running (Figure 5)

The graphic pattern of potential activity for the three muscles under investigation during running and walking are quite similar. The least amount of activity was found to be just before and during push-off.

The gluteus maximus makes a negligible contribution to the whole walking pattern. Its trace-to-mild potential activity is recorded immediately after the heel contacts the ground for one-third of the supporting phase. During the run it seems to be involved over a longer part of the contact phase.

The semitendinosus and biceps femoris become active in the final third of the swinging phase of the walk and remain active through the first third of the stance phase. During the run, the semitendinosus records potential activity throughout most of the swinging phase. In general the data support findings of other researchers who have studied the walk. Eberhart, and associates have recorded more extensive muscular involvement of the walk.

Vertical jump for maximum height (Figure 3)

Potential activity was recorded between mild and moderate for the gluteus maximus during the preparatory and push-off phases of the vertical jump for height. During extension and contact only slight deflection of the potentials was evident. After contact, when the body began righting itself to the standing position, trace to mild readings were recorded. A somewhat opposite pattern was recorded for the hamstrings. Little activity was seen during the push-off phase. Just before contact mild, plus was recorded by the semitendinosus. The electrical activity to the regaining of the standing position was limited but similar to that of the gluteus maximus.

Bench stepping exercise (Figure 6)

On the step up, as the body was raised upward, the gluteus maximus recordings

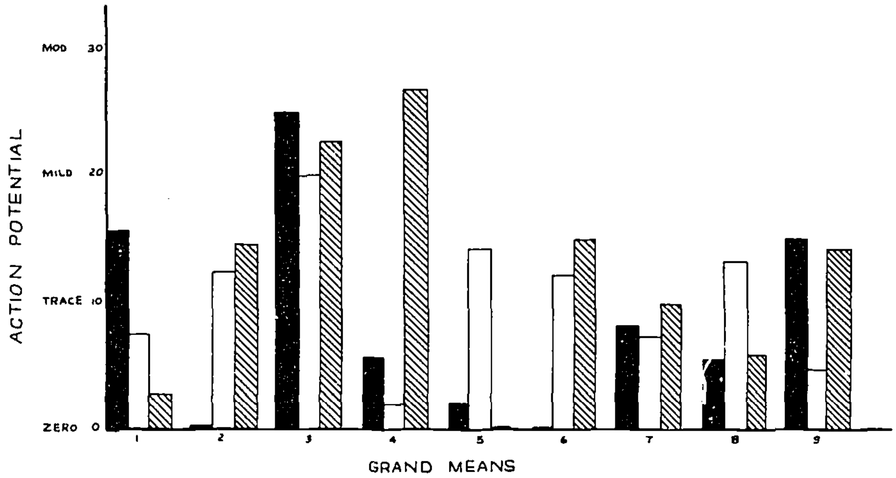

Figure 3. Total movement patterns for all subjects.

☐ *Semitendinosus* ▨ *Biceps femoris* ■ *Gluteus maximus*

1. Abduction
2. Adduction
3. Extension
4. Lateral rotation
5. Medial rotation
6. Pelvic tilt
7. Bicycle
8. Treadmill
9. Vertical jump

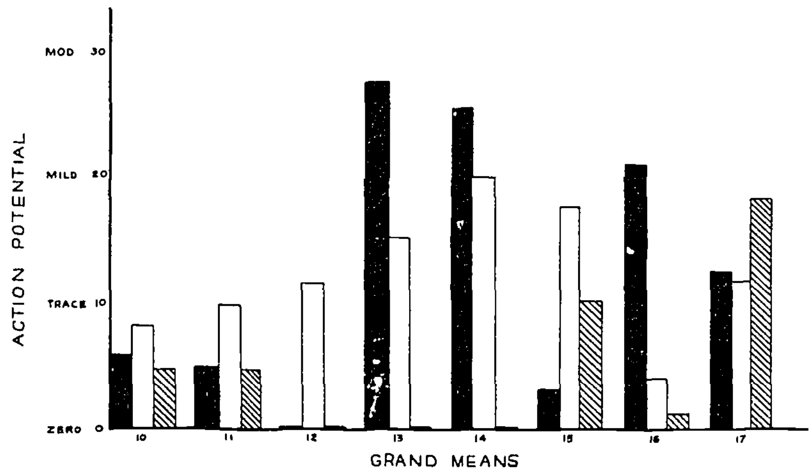

Figure 4. Total movement patterns for all subjects.

☐ *Semitendinosus* ▨ *Biceps femoris* ■ *Gluteus maximus*

10. Stepping up
11. Toe touch
12. Lean forward
13. Prone isometric
14. Supine isometric
15. Adduction isometric
16. Abduction isometric
17. Extension pulley resistance

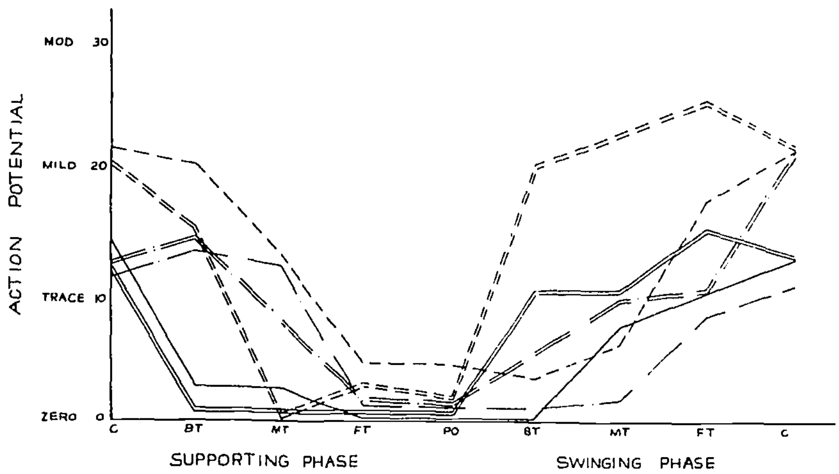

Figure 5. Mean readings in treadmill walking. *Biceps femoris* ———; *Gluteus maximus* — . —; *Semitendinosus* — — —

Mean readings in treadmill running. *Biceps femoris* = ==; *Gluteus maximus* = : =; *Semitendinosus* = = =

C - Contact; BT, MT, FT - Beginning, middle, final third; PO - Push-off

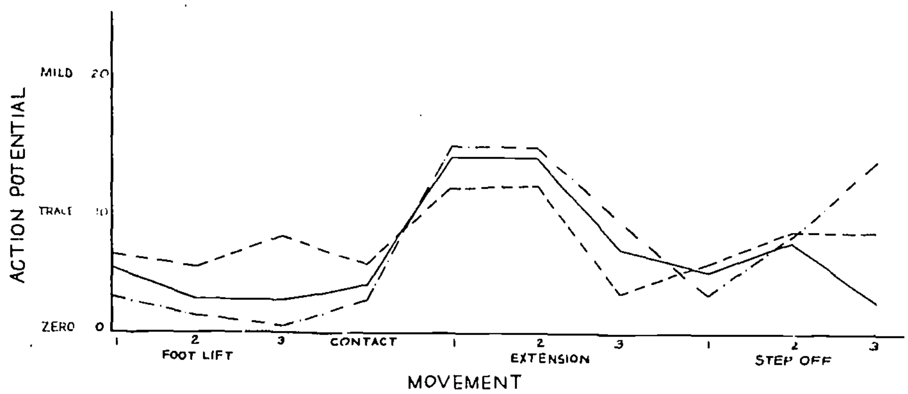

Figure 6. Mean readings in bench step. *Biceps femoris* ———; *Gluteus maximus* — . —; *Semitendinosus* — — —

Movement in each phase, foot lift, extension, and step-off was broken into three parts to show gradual change in hip action (slow motion filming). During step-off phase, weight supported on test leg.

were rated as mild. There was no potential activity before this during the actual preparation phase nor at moment of contact with the step. On the stepping down phase, no activity was recorded until the foot contacted the floor at which time a trace, plus potential recording was made. The hamstrings show a somewhat similar pattern with additional recordings made during times when the knee was flexed. In this exercise as in some of the other exercises, a difference in activity pattern was found between the two hamstring muscles.

Bicycle riding exercise (Figure 7)

Limited potential activity was observed for the three muscles during the bicycling exercise. The gluteus maximus was mildly active during the power phase as the foot began pushing down on the pedal. (Thigh approximately 60° from vertical extension of 0°.) This activity appeared to last only a few degrees in the downward cycle and then ceased. The hamstrings showed slight involvement throughout most of the cycle of movement. Phases of inactivity for the two hamstring muscles were not synchronous.

Houtz and Fisher (5) found the gluteus maximus to be completely inactive throughout the movement and the hamstrings to make a negligible contribution as the foot was underneath the body. Bicycling requires primarily hip flexors, knee extensors, and foot and ankle muscles.

Balance activities (Figure 4)

Toe touching and body-sway-forward were exercises used to determine the effectiveness of the three hip extensors in regaining balance. Only the recordings for one subject were available for these tests. When the subject swayed forward from a standing position no activity was recorded for the gluteus maximus. The semitendinosus did have a reading of trace, plus to mild when the body nearly lost its balance forward. Joseph (8) found a similar response from these muscles. He found no activity from the gluteus maximus but considerable potential activity was recorded for the hamstrings. Jonsson (7) found no gluteus maximus activity in the body sway.

During the standing and toe touching phases of the toe touching exercise, the electrical activity was zero for the three muscles.

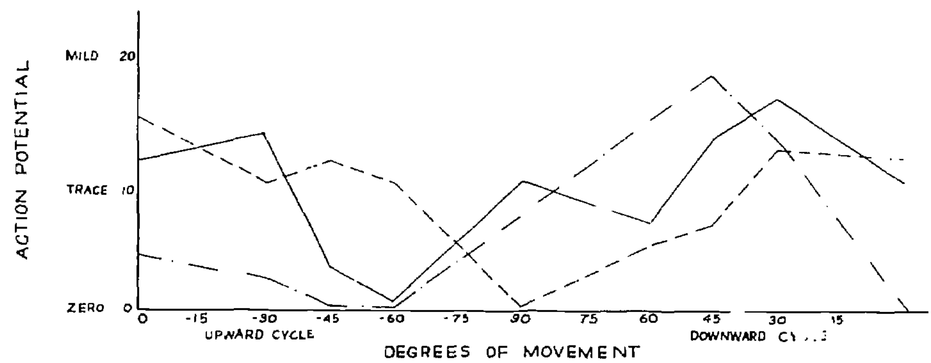

Figure 7. Mean readings in bicycle riding, sitting. *Biceps femoris* ———; *Gluteus maximus* — . —; *Semitendinosus* — — —

At 0° thigh is in extension; 90° thigh is in flexion.

During the actual movements of bending forward and straightening up trace activity was recorded by all three muscles.

SUMMARY AND CONCLUSIONS

Electromyographic recordings of the gluteus maximus, semitendinous, and biceps femoris were recorded simultaneously with motion picture studies of subjects performing a variety of movements involving the hip joint. An evaluation of the differential activity of the hamstrings and gluteus maximus was made as well as a graphical representation of the muscle action during the various phases of the movements.

The evidence presented supports the following conclusions:

1. During exercise, the hamstrings initiate and control backward extension of the thigh when forward of the neutral position, and adduct the thigh. The biceps femoris is a strong lateral rotator of the thigh and the semitendinosus is a strong medial rotator. Neither muscle is an abductor.

2. The gluteus maximus works most efficiently as a thigh extensor when working against resistance and when the thigh moves beyond neutral position into hyperextension.

3. The gluteus maximus abducts the thigh when held in any position, may contribute slightly to lateral rotation, but is neither an adductor nor medial rotator of the thigh.

4. The activities selected for this study which involve the gluteus maximus to the greatest extent are: stair stepping, vertical jump, isometric contraction, and hyperextension (particularly against resistance). Those requiring minimal effort on the part of the gluteus maximus are walking, running, bicycling, standing, and the maintenance of balance.

5. Variability in potential activity of a muscle during various phases of an activity indicates the independence of muscle action and emphasizes the individual responsibility of muscles in the execution of coordinated movements.

References

1. Basmajian, J. V. *Muscles alive*. Baltimore: Williams and Wilkins Co., 1962.
2. Close, J. R. *Motor functioning in the lower extremity*. Springfield, Ill.: Charles C. Thomas, 1964.
3. Eberhart, H. D., and OTHERS. *Fundamental studies on human locomotion and other information relating to design of artificial limbs*. A report to the National Research Council, Committee on Artificial Limbs. University of C: rnia, Berkeley, 1947.
4. Fli.., M. Marilyn. Photo-recording electromyography in clinical kinesiological studies. *Biomechanics* I, First International Seminar, Zurich, 1967. Basel/New York: S. Karger, 1968, pp. 132-37.
5. Houtz, S. J., and Fischer, F. J. An analysis of muscle action and joint excursion during exercise on a stationary bicycle. *Journal of Bone and Joint Surgery* 41-A: 123-31, 1959.
6. 'nman, Verne T. Functional aspects of the abductor muscles of the hip. *Journal of Bone and Joint Surgery* 29:607-619, 1947.
7. Jonsson, Bengt, and Synnerstad, Bjorn. Electromyographic studies of muscle function in standing. *Acta Morphologica Neerlando-Scandinavica*. 6:361-70, 1966.
8. Joseph, J. *Man's posture—electromyographic studies*. Springfield, Ill.: Charles C. Thomas, 1960.
9. Levine, Milton G., and Kabot, Herman. Dynamics of normal voluntary motion in man. *Permanente Foundation Medical Bulletin* 10: 212-36, August 1952.
10. Markee, Joseph E., and OTHERS. Two joint muscles of the thigh. *Journal of Bone and Joint Surgery* 37-A:125-42, 1955.
11. Wells, Katherine F. *Kinesiology*. Philadelphia: W. B. Saunders Co., 1966. p. 315.
12. Wheatley, Max D., and Jahnke, William D. Electromyography study of the superficial thigh and hip muscles in normal individuals. *Archives of Physical Medicine* 32:508-15, 1951.

GLADYS E. GARRETT
CAROL J. WIDULE

Kinetic Energy: A Measure of Movement Individuality

AS A CHILD MATURES, his movement behavior undergoes both quantitative and qualitative changes. While these changes may be detected by the trained eye, quantification is necessary for future reference and comparison. Previous investigators of the mechanical characteristics of human motion have used measures of the body and body segments such as displacement, velocity, inclination, and slope (2, 7, 8, 10). A measure of human motion less frequently used is kinetic energy, which Eckert (5) claims is a next step in improving the accuracy of analyses in the study of human movement. One of the parameters necessary in kinetic energy analysis is the moment of inertia of each body part. Experimental methods for determining moments of inertia have been described in the literature (1, 3, 4, 9).

To a scientist, energy expenditure is synonymous with motion. Since by definition a moving body is said to posses energy of motion, or kinetic energy, kinetic energy would appear to be an appropriate measure of movement of the human body. This study was undertaken to explore the possibility of using kinetic energy as a measure capable of distinguishing individual differences in performance.

Gladys E. Garrett is an assistant professor and Carol J. Widule an associate professor at Purdue University, Lafayette, Indiana. The study is based on a Ph.D. dissertation of G. Garrett, under the supervision of C. Widule, major professor, January 1970.

Kinetic energy analysis

Any body that is rotating about an axis not passing through its center of gravity may be considered to have a motion of translation and a motion of rotation about its center of gravity combined. The body shown in Figure 1, which may represent a human limb or segment, may be considered to be made up of a translation with the velocity Vcg of the center of gravity and a rotation ω about the center of gravity.

The kinetic energy of the body can be represented by the following expression:

$$KE_i = \tfrac{1}{2} M_i \, Vcg_i^2 + \tfrac{1}{2} Icg_i \, \omega_i^2$$

where the subscript, i, represents the i^{th} segment of a system, and where

M = mass of segment in units of $\frac{\text{lb-sec}^2}{\text{in}}$

Vcg = velocity of the center of gravity of segment in units of $\frac{\text{in}}{\text{sec}}$

Icg = mass moment of inertia of the segment about its center of gravity in units of $\frac{\text{in-lb-sec}^2}{\text{rad}^2}$

ω = angular velocity of the segment in units of $\frac{\text{rad}}{\text{sec}}$

The units of kinetic energy as shown in the following check of units are in-lbs.

$$KE = \tfrac{1}{2} M \, Vcg^2 + \tfrac{1}{2} Icg \, \omega^2$$

$$\text{in-lbs} = \frac{\text{lb-sec}^2}{\text{in}} \times \frac{\text{in}^2}{\text{sec}^2} + \frac{\text{in-lb-sec}^2}{\text{rad}^2} \times \frac{\text{rad}^2}{\text{sec}^2}$$

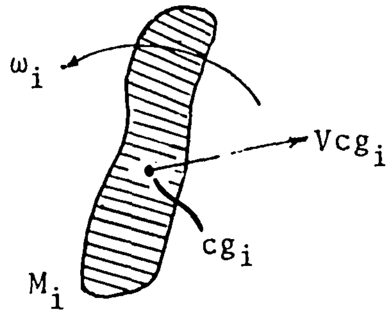

Figure 1. Notation of i^{th} segment.

Since each segment of the subject's body is represented by its center of gravity (which is assumed to be the center of the distributed mass), it was first necessary to compute the x and y coordinates of the segment center of gravity. This was accomplished by multiplying the difference between the respective coordinates by the center of gravity proportionality factor (CGP) as obtained from Dempster (4).

For example, the coordinates of the center of gravity of segment number three, which is bounded by joint numbers three and four, would be obtained by

$$CGX_3 = CGP_3\,(X_4 - X_3) + X_3$$
and $$CGY_3 = CGP_3\,(Y_4 - Y_3) + Y_3.$$

The sources of other information for the necessary inputs to the kinetic energy equation were as follows:

1. M (mass) $= \dfrac{w}{g}$

$$= \frac{\text{weight of segment}}{\text{acceleration of gravity}}$$

The weights of the segments were obtained by multiplying the segmental weight proportions of Braun and Fischer (11) by the subject's total body weight. The acceleration of gravity is 386.4 in/sec^2.

2. V (velocity)

The velocities of the centers of gravity were obtained by numerically differentiating the center of gravity displacement information with the aid of a finite difference technique. Specifically, the second central difference expressions for velocity components were used. This expression tends to give more accurate results for experimental data, since it takes a look at displacements up to two stations to the right and two stations to the left of each position being analyzed.

$$Vcgx_j = [-CGX_{j+2} + 8(CGX_{j-1}) - 8(CGX_{j-1}) + CGX_{j-2}]/12DT$$
$$Vcgy_j = [-CGY_{j+2} + 8(CGY_{j-1}) - 8(CGY_{j-1}) + CGY_{j-2}]/12DT$$

where DT is the time increment between positions.

The total velocity for the center of gravity at that position is given by

$$Vcgj = \sqrt{(Vcgx_j)^2 + (Vcgy_j)^2}$$

3. ω (angular velocity)

The angular position, θ, of each segment at each position is given by the trigonometric relationship

$$\tan \theta_3 = \frac{Y_4 - Y_3}{X_4 - X_3}$$

for the case of segment number three.

The angular velocity of segment three is then obtained by

$$\omega_3 = \frac{\theta_3(\text{at station j}) - \theta_3(\text{at station j}-1)}{DT}$$

4. I (moments of inertia of body segments)

The units of the moments of inertia of body segments in Dempster were found to be weight moments of inertia (gm cm^2). To get mass moments of inertia these units had to be divided by g(980 cm/sec^2). Therefore

$$Icg_m = \frac{\text{gm cm}^2\ \text{sec}^2}{980\ \text{cm}} = \frac{\text{gm cm sec}^2}{980}$$

which was found to be analogous to lb-in sec^2 in U. S. measure.

In order to get the units in lb-in sec^2 the following formula was used with Dempster's values (DV):

Given 1 gm = .0022 lbs
1 cm = .3937 in

Therefore

$$\frac{DV \times .0022\ \text{lbs} \times .3937\ \text{in sec}^2}{980} = \text{U. S. Measure}$$

$$\frac{DV \times 2.2 \times 10^{-3} \times .3937}{980 \times 10^3} = \text{U. S. Measure}$$

$$DV\ .844 \times 10^{-6} = \text{U. S. Measure}$$

Since Dempster's values are in the form gm $cm^2 \times 10^6$, they were used directly (without the 10^6) and multiplied by .884.*

The preceding analytics provided the basis for a computer program which subsequently resulted in the calculation of the segmental kinetic energies as well as the total body kinetic energy of the subject at the three ages.

Data collection procedures

A film record of a boy subject executing a jump from a 12-inch bench was obtained at the ages of two, three, and four years. From the image projected by a Griscombe Microfilm Reader, the rectangular coordinates were obtained for each of the following locations on the body: toes, ankles, knees, hips, shoulders, top of head, elbows, wrists, and fingers. The coordinates were obtained from frames selected at intervals of approximately .05 seconds, from approximately .25 seconds prior to take-off to the moment of landing.‡

The segmental and total body's centers of gravity were calculated from the basic geometric data obtained from the film records, and the discrete data points were modeled using the finite difference technique. From the modeled data, corresponding moments in time could be determined between the intial frame and final frame, for the three ages. Kinetic energy values were derived from the modeled data.

TABLE 1. VELOCITY AND KINETIC ENERGY OF THE LEFT FOOT FOR EACH FRAME

Positon	Segment	End 1	End 2	Vel CG	Omega	K. E.
3	1	1	2	3.981	−5.437	.354
4	1	1	2	6.825	.795	.048
5	1	1	2	9.817	−2.399	.151
6	1	1	2	6.786	−.047	.040
7	1	1	2	7.210	.289	.047
8	1	1	2	7.568	−3.622	.201
9	1	1	2	11.722	−2.220	.177
10	1	1	2	3.572	3.478	.150
11	1	1	2	27.176	2.723	.734
12	1	1	2	47.492	−13.199	3.982
13	1	1	2	33.612	−6.431	1.467
14	1	1	2	24.155	−.829	.520
15	1	1	2	47.073	.979	1.956
16	1	1	2	58.937	1.609	3.079
17	1	1	2	81.196	−4.323	6.002
18	1	1	2	97.566	7.963	9.085
19	1	1	2	80.848	9.331	6.738
20	1	1	2	64.016	4.879	3.871
21	1	1	2	69.964	−1.804	4.334
22	1	1	2	96.686	−.445	8.209
23	1	1	2	77.298	1.633	5.276
24	1	1	2	29.018	4.155	.938
25	1	1	2	6.063	−5.965	.441
26	1	1	2	6.985	2.762	.131
27	1	1	2	16.758	−3.221	.366
28	1	1	[illegible]	.250	−1.490	.026
29	1	1	2	11.050	.293	.108

* See Garrett (6:68) for corrected moment of inertia values.

‡ For details related to the photographic situation, the film speeds, and linear conversion factors, see Garrett (6).

TABLE 2. ENERGY DISTRIBUTION IN THE SEGMENTS ON PERCENTAGE BASIS — AGE TWO

	LFoot	LLeg	LThi	RThi	RLeg	RFoot	LHand	L4Arm	LUArm	RUArm	R4Arm	RHand	Trunk	Total K E.
3	2.64	8.84	4.78	5.96	1.52	.29	.88	4.31	7.97	28.93	4.92	5.17	23.80	13.422
4	.46	2.25	3.04	29.92	.08	.68	.43	3.17	3.75	6.86	7.59	6.55	35.01	10.519
5	1.36	2.08	.59	5.59	.89	.27	.54	3.58	2.89	30.68	21.45	14.49	15.48	11.103
6	.48	2.40	12.29	14.36	3.49	.32	1.35	1.38	7.72	11.93	17.60	25.40	1.28	8.374
7	.08	.55	15.02	6.59	.63	.02	.06	.51	.63	2.26	2.01	4.58	67.05	56.329
8	.51	1.58	15.52	2.94	.17	.03	.83	2.02	4.48	4.95	5.84	8.34	52.80	39.355
9	.74	1.89	5.17	2.48	.12	.07	2.51	4.90	10.63	8.82	8.98	13.99	39.90	23.900
10	.62	19.08	12.19	1.62	.62	.13	5.81	9.63	6.23	2.37	6.10	11.89	23.70	24.338
11	1.81	5.38	11.56	4.15	1.04	.30	4.48	10.59	9.39	3.58	5.15	6.84	35.70	40.574
12	6.28	22.84	8.89	7.70	.71	.15	3.25	8.34	5.75	5.57	3.60	4.39	22.53	53.331
13	5.09	7.21	7.17	6.25	6.77	.37	6.13	13.73	6.04	4.07	4.12	6.97	25.97	28.820
14	.87	2.57	9.57	6.91	1.25	.16	2.20	5.11	8.32	.25	1.12	2.77	58.93	69.977
15	1.85	4.16	14.56	11.41	2.51	.76	1.15	3.50	1.67	1.33	1.23	.92	54.86	105.793
16	3.36	9.27	7.78	8.38	6.23	.57	.06	.92	3.25	.85	1.16	.57	57.49	91.663
17	5.87	7.85	3.06	17.88	6.43	2.38	.60	1.80	4.17	4.24	2.58	2.43	40.71	102.323
18	5.37	9.02	5.93	9.23	3.61	2.29	.68	2.18	2.24	3.63	4.09	4.49	47.24	169.071
19	3.52	8.01	9.27	6.45	6.72	4.89	1.31	3.93	4.27	4.76	5.26	9.04	32.57	191.604
20	1.52	2.85	5.21	6.93	8.76	5.02	1.68	5.39	4.65	12.85	7.26	9.44	28.44	254.268
21	1.09	1.95	4.76	6.19	5.89	2.52	1.03	2.83	3.15	37.23	4.62	5.79	23.15	398.054
22	2.49	5.53	10.90	10.91	6.18	2.87	.84	2.78	3.00	3.57	4.30	5.96	40.67	330.169
23	1.16	4.21	12.37	13.53	4.69	1.26	.50	2.18	3.40	3.34	3.32	3.47	46.57	456.619
24	.35	5.64	9.04	7.91	4.03	.60	.62	2.79	4.03	4.49	5.26	4.50	50.76	270.541
25	.22	.24	18.59	23.07	1.11	.14	1.73	4.80	4.53	5.75	3.94	3.76	32.12	200.742
26	.06	.33	1.00	.78	.60	.02	1.28	3.92	7.86	5.20	2.85	3.28	72.82	202.500
27	.86	3.01	10.87	8.22	2.23	.72	2.05	7.49	1.92	1.54	4.36	4.99	51.75	42.332
28	.03	.38	2.54	1.70	.78	.16	.75	1.30	.52	2.61	1.28	1.68	86.26	83.353
29	.07	.46	5.98	2.51	.74	.06	.36	1.95	1.92	3.74	3.81	2.80	75.60	157.056

Results and discussion

Table 1 is an example of the results obtained from the computer program of the linear velocity of the center of gravity of a segment, the angular velocity of the segment, and the kinetic energy of the segment for each frame used in the analysis (with the exception of the first two and last two frames which are "lost" when using the second central difference expression to calculate velocity). A similar page was obtained for each segment for the three ages. For the sake of brevity, only one page has been included.

The relative increase and decrease in kinetic energy of the segment can be noted in these records. Fluctuations in the kinetic energy values are probably due to error still present in the modeled data.

Table 2 is an example of the results of the total kinetic energy of the body and of the percent of kinetic energy of the segments in relation to the total for each frame for age two. For example, the 16th frame, which is the take-off frame for the two-year-old, discloses that about three percent of the total kinetic energy at this moment can be attributed to the left foot, about nine percent to the left leg, about seven percent to the left thigh, etc. It must be remembered that these are merely percentages of the total kinetic energy and not absolute values in themselves. Results were also obtained for ages three and four but have not been included.

A study by Glassow, and others (7) indicated that greater angular velocities of the thighs and trunk at take-off result in better jumping performance. The results of this analysis substantiate the findings of Glassow as far as the thighs are concerned, but do not concerning the trunk. In Table 3 are the angular velocities of the thighs and trunk at take-off at ages two, three, and four. The kinetic energy developed by the thighs at take-off is given in Table 4.

A plot of total body kinetic energy versus time for the three ages studied can be seen in Figure 2. The curves were so positioned that take-off occurred at a common instant in time in order to allow for some related observations. It can definitely be said that the energy level increased with age. Since the same moment of inertia of the total body is used for the three ages, and since the body weight increased only slightly — from 32 to 36 pounds — the increase in energy is directly attributable to the segmental speed developed. It is interesting to note that the kinetic energy has reached a peak at take-off at the ages of three and four, where the performance was better. Also, the smoothness of the kinetic energy curve at age four would appear to be a result of a smoother, more totally integrated jump. It was also found that in the jump at this age the upper limbs constituted a larger percentage distribution than did the lower limbs before take-off. Upon take-off, however, a definite reversal of this situation was noted. Does this mean that the upper limbs play an important role in developing the energy necessary for a skillful take-off? Answers to questions such as this will not be known until more extensive investigations are performed on more subjects. Hopefully, the analysis techniques presented here will provide a vehicle for pursuing the answers to questions of this type.

Because a change in the kinetic energy was reflected as the child matured in his jumping pattern, kinetic energy shows promise as a measure of movement individuality. The results of the study warrant additional research of the energy characteristics of human motion.

TABLE 3. COMPARISON OF ANGULAR VELOCITIES (rad/sec)

Age	Left Thigh	Right Thigh	Trunk
2	3.0	0	2.6
3	−8.7	−5.0	2.0
4	−5.0	−6.5	1.7

TABLE 4. COMPARISON OF THE KINETIC ENERGY OF THE THIGHS

Age	Left Thigh	Right Thigh
2	7	18
3	38	37
4	48	55

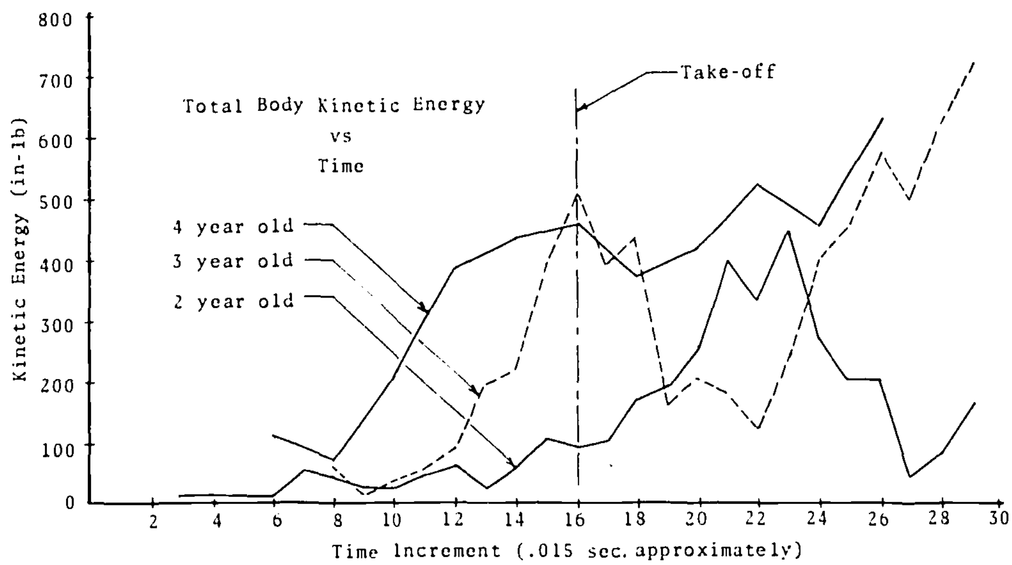

Figure 2. Total body kinetic energy for each frame at ages two, three, and four.

References

1. Bouisset, S., and Pertuzon, E. Experimental determination of the moment of inertia of limb segments. In J. Wartenweiler; E. Jokl; and M. H. Hebbelinck (Eds.), *Biomechanics II*. Basel, Switzerland: S. Karger, 1968, pp. 106-109.
2. Cooper, John M., and Glassow, Ruth B. *Kinesiology*. St. Louis: C. V. Mosby, 1968.
3. Damon, Albert; Stoudt, Howard W.; and McFarland, Ross A. *The human body in equipment design*. Cambridge, Mass.: Harvard University Press, 1966.
4. Dempster, W. T. *Space requirements of the seated operator*. WADC Technical Report 55-159, Aero Medical Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio, 1955.
5. Eckert, Helen. A. concept of force-energy in human movement. *Journal of American Physical Therapy Association* 45:213-18, 1965.
6. Garrett, Gladys E. Methodology for assessing movement individuality: A computerized approach. Doctoral dissertation, Purdue University, 1970.
7. Glassow, Ruth B.; Halverson, Lolas E.; and Rarick, G. Lawrence. *Improvement of motor development and physical fitness in elementary school children*. Cooperative Research, Project No. 696, University of Wisconsin, Madison.
8. Hellebrandt, F. A., and others. Physiological analysis of basic motor skills. I. Growth and development of jumping. *American Journal of Physical Medicine* 40:14-25, 1961.
9. Holowenko, A. R. *Dynamics of machinery*. New York: John Wiley and Sons, 1955.
10. Kessen, William; Hendry, Louise S.; and Leutzendorff, Anne-Marie. Measurement of movement and the human newborn: A new technique. *Child Development* 32:95-105, 194. 194.
11. Woods, Bryan Duncan. *Validity of the segmental method of assessing the position of the center of gravity of the body in the supine position*. Master's thesis, University of Oregon, Eugene, 1967.

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ANGLCALC: A Computer Program for Descriptive Analysis of Movements Used During Repeated Performances of Skills

THE OBSTACLES TO THE CONDUCT of comprehensive cinematographic movement analyses have been sufficient to discourage researchers from filming subjects over a series of repeated performances of a skill. Rather than recording longitudinal data on subjects, kinesiologist-cinematographers have found it more feasible to photograph each individual as he performs a limited number of trials and to consider this small sampling of behavior representative of the subject's movement characteristics. Generally, a large number of filmed trials for each performer is sacrificed so that a greater number of subjects can be studied.

In selecting only a few trials for analysis, the experimenter ignores the likely possibility that individual performance styles vary markedly from trial to trial. A representative performance style may be attributed more accurately to an individual if the description is based on observations made over a mulitude of trials rather than one or two isolated attempts.

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A serious consequence of the kinesiologist's hesitancy to conduct longitudinal investigations has been the retardation of meaningful integration of kinesiological and motor learning research. Rather than studying relationships between movements and learning, kinesiologists have focused primary attention on problems requiring the application of Newtonian laws to human movement in an attempt to understand more fully the mechanical bases for efficient performance in specialized athletic tasks. Consequently, knowledge is lacking concerning the effects of practice on component movements of gross motor tasks, the stability of individual performance techniques over repeated trials, or the nature and order of changes in movements that occur during learning of motor skills.

The primary deterrent to longitudinal cinematographic studies has been the volume of physical work represented by the process. Even where a small number of measurements are to be recorded for a few subjects, the data extracted multiply in direct proportion to the number of trials included in the experiment. For example, when information concerning the position for five subjects in three different frames on five consecutive trials is desired, 75 separate frames must be analyzed. If the subjects are to execute 10

trials the number of frames to be analyzed doubles to 150. The investigator who naively tackles such a problem soon realizes he has created a project of monstrous proportions, while the sample size and number of trial repetitions are still embarrassingly small.

In order to make feasible the conduct of longitudinal studies, the computer program — ANGLCALC — has been written. This program expedites collection of data from film records while eliminating much of the measurement error associated with manual analyses. ANGLCALC provides a descriptive rather than mechanical account of the movements used by subjects during repeated executions of a skill. Angles are calculated for the hip, knee, ankle, and metatarsal-phalangeal joints and for the inclination (with the horizontal) of the trunk, thigh, leg, and foot. The angles of inclination are calculated to the right of the segment, as illustrated in Figure 1. The program is designed to take measurements on each of the eight variables from three separate frames on each trial. Any number of subjects (in multiples of 10) may execute any number of trials (in multiples of 10).

For convenience, the trials are divided into three sets of 10 each and labelled: Session I, Session II, etc. Subroutines calculate the mean measurement on the variables for each subject on the first 5, last 5, and entire 10 trials in each session. In addition, the standard deviation of the measurements for each subject is calculated, as is the variance between the subject means for each set of 10 trials. Blocking the trials into sessions facilitates statistical comparison of subject performances on early and late trials.

The method of collecting the data for input is similar to the technique suggested by Rushall and Pyke (2). A laminated coordinate grid 15″ x 15″ and calibrated along X and Y axes at 40 parts to the inch is mounted on the viewing screen of a Recordak P-40. Locations of relevant anatomical landmarks are plotted directly on the grid surface with a fine-tip ink indicator. Coordinate readings for the landmarks are transcribed on data sheets for key punching. The ink marks then are erased from the

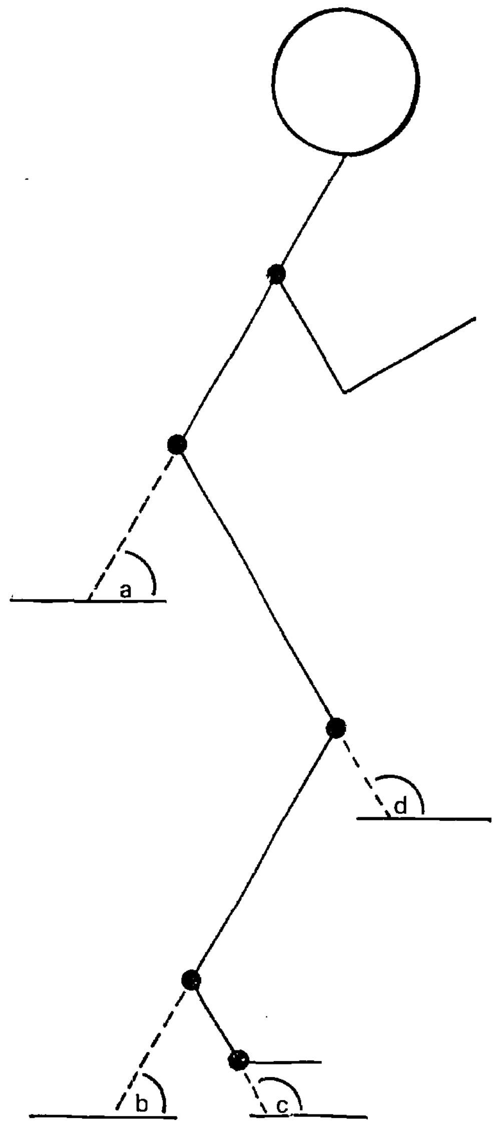

Figure 1. Angles of inclination of body segments with the horizontal as calculated with ANGLCALC. a) Trunk, b) leg, c) foot, d) thigh.

	SUBJECT	FRAME	SESSION	TRIAL		SHOULDER X	SHOULDER Y	HIP X	HIP Y	KNEE X	KNEE Y	ANKLE X	ANKLE Y	M-P X	M-P Y	TOE X	TOE Y	REFERENCE 1 X	REFERENCE 1 Y	REFERENCE 2 X	REFERENCE 2 Y
CARD 1	1	1	1	1		179	197	202	124	149	104	180	51	169	35	159	33	200	356	497	350
CARD 2	1	2	1	1		214	284	223	193	189	147	179	85	162	70	150	69	196	386	494	380
CARD 3	1	3	1	1		290	274	275	189	257	134	306	99	307	79	300	74	196	394	492	387

Figure 2. Format for data input. Coordinates for each frame are punched on separate cards. Data in illustration are for the backward standing jump for distance. Frame 1 occurred at .15 seconds prior to take-off; Frame 2 occurred at take-off, and Frame 3 at landing.

laminated grid surface with a moist cloth. The process of transcribing the data can be speeded up considerably if an assistant is available to record the data as it is read aloud by the investigator. Using the team approach, the data can be collected and recorded in reliable fashion at a rate of approximately one minute per frame of film.

Data is input as subject, trial, frame, and session followed by X and Y coordinates for the shoulder, hip, knee, ankle, metatarsal-phalangeal joint, and tip of toe. Coordinates for all anatomical landmarks and coordinates for two constant background reference points which lie on a horizontal plane in the visual field also must be input for each frame (Figure 2 illustrates the format used for inputting the data). The fer-ence points are used to calculate a correction factor for slight rotation of the projected image on the grid surface.

The output is arrayed in tables where the data for all 10 subjects for an entire block of 10 trials are displayed for each variable under examination. Figure 3 illustrates a display of sample output from data taken on the angle at the hip and angle of inclination of the trunk for 10 subjects during one frame on the first 10 of 30 trials in the standing broad jump. In an experiment where 10 subjects execute 30 jumps and measurements on all eight variables are collected for three frames on each trial, a total of 72 such tables is printed. If the camera speed is known, average angular velocities can be computed by calculating the difference in joint positions between relevant frames and multiplying by the appropriate reciprocal.

Currently, ANGLCALC is being used at the University of Nebraska at Omaha to investigate the effects of practice on alterations in component movements of motor tasks. The subroutines for calculating the standard deviation of individual measurements and variance between subject means has been particularly useful for investigating problems related to intra- and inter-individual variability in movement. While the program has been used primarily for analyzing movements used in jumping, it appears readily adaptable for analysis of any skills which consist of uniplanar motions.

ANGLE AT HIP SESSION NO 1 FRAME 2

TRIAL=	1	2	3	4	5	6	7	8	9	10	MN-1-5	MN-6-0	MN-1-0	STD DEV
S= 0	147.82	131.58	150.50	131.0	122.54	148.86	131.61	116.05	130.86	122.65	136.69	130.01	133.35	11.3702
S= 1	128.05	130.82	130.01	141.75	124.04	140.73	130.62	108.25	131.64	109.19	130.93	124.09	127.51	10.6798
S= 2	130.78	138.30	136.01	136.10	136.10	141.00	135.15	133.85	137.94	135.24	134.67	136.44	135.65	2.8380
S= 3	135.05	108.68	94.60	109.19	114.89	138.87	123.55	113.99	122.27	120.79	112.48	123.89	118.19	12.3305
S= 4	138.54	123.78	126.30	119.01	108.60	113.01	122.52	105.60	122.08	97.64	123.25	112.17	117.71	11.1487
S= 5	120.83	123.05	126.71	110.99	129.87	119.34	112.23	120.23	132.10	116.77	122.29	120.13	121.12	6.6081
S= 6	149.64	87.45	[illegible]5.99	144.99	148.33	137.42	153.63	154.65	145.97	141.15	137.48	146.56	142.02	19.0801
S= 7	136.46	135.17	144.93	138.03	116.46	134.81	144.09	135.93	148.96	145.63	134.21	141.89	138.05	8.6728
S= 8	145.12	147.05	131.93	137.63	142.04	127.32	43.47	143.38	130.16	140.95	140.75	117.06	128.90	29.1678
S= 9	160.46	127.07	133.76	124.40	119.32	133.27	130.65	149.36	124.19	114.90	133.00	130.47	131.74	13.0886

INCLNTN ANGLE AT HIP SESSION NO 1 FRAME 2

TRIAL=	1	2	3	4	5	6	7	8	9	10	MN-1-5	MN-6-0	MN-1-0	STD DEV
S= 0	103.42	109.65	102.32	111.56	121.33	100.81	107.43	113.77	113.89	112.04	109.66	109.59	109.62	5.9681
S= 1	114.62	112.62	112.28	106.77	111.54	103.88	110.16	128.77	110.64	121.22	111.57	114.93	113.25	6.7571
S= 2	104.71	107.43	104.74	103.28	110.34	93.69	103.89	111.37	100.58	104.65	106.10	102.84	104.47	4.7339
S= 3	101.77	120.82	135.00	118.41	119.36	99.33	116.94	114.38	114.04	111.80	119.07	111.30	115.19	9.4421
S= 4	98.04	103.24	104.74	112.04	113.11	111.32	114.86	119.40	117.45	126.03	106.23	117.81	112.02	7.8452
S= 5	107.62	103.31	113.67	118.72	104.60	110.48	109.41	115.02	109.21	108.23	109.58	110.47	110.03	4.4567
S= 6	99.46	155.56	96.79	102.42	98.60	101.96	91.93	85.03	90.60	98.38	110.54	93.58	102.06	18.5629
S= 7	111.37	109.12	104.74	109.80	124.29	109.52	108.43	109.29	100.71	97.37	111.86	105.07	108.46	6.7803
S= 8	107.35	103.36	115.24	106.63	104.38	111.56	100.24	101.71	109.52	106.57	107.39	105.92	106.66	4.3356
S= 9	94.29	118.97	106.99	108.92	111.25	112.46	109.60	104.42	116.57	121.12	108.08	112.83	110.46	7.3555

Figure 3. Array of data in output for ANGLCALC. "INCLNTN AT HIP" refers to angle of inclination of trunk with the horizontal. (Tabulation of the variance between the means has been omitted from the illustration.)

Calculation of the angle of slope of major body segments is an especially valuable function. For some time kinesiologists have recognized that joint angles alone do not depict the relative positions of the body segments during movement. In an early study of the standing broad jump, Johnson first pointed out that motion at any joint alters the relative position of all body segments above the joint (1). If an analytical strategy is to furnish a complete account of the movements of the body through space it should indicate the position of body segments with respect to the horizontal as well as the angles formed at joints.

With minor modifications, the use of ANGLCALC can be extended to undergraduate and graduate courses of instruction in kinesiology. It is becoming increasingly common for kinesiology instructors to require their students to conduct elementary cinematographic analyses as course projects. The unglamorous task of tracing and measuring angles frequently makes such assignments exercises in perseverance rather than meaningful studies in movement. With ANGLCALC the sophistication and scope of course projects can be increased while the student will have available more time for interpretation and application of his findings.

NOTE: ANGLCALC was written in Fortran IV language specifically for the NCR 315 RMC computer. Disc accessing routines are from the University of Nebraska at Omaha Computer Center program library. Application of ANGLCALC to other systems will require minor modifications. Copies of the program may be obtained by writing to: Shirl James Hoffman, Department of Physical Education for Men, University of Nebraska at Omaha, P. O. Box 688, Omaha, Nebraska 68101.

References

1. Johnson, Barbara. *An analysis of the mechanics of the standing broad jump.* Master's thesis, University of Wisconsin, 1957.
2. Pyke, Frank, and Rushall, Brent. *A computer analysis of skills of projecting objects.* Paper presented at Kinesiology Section, AAHPER National Convention, Boston, April 1969.

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A Three-Dimensional Human Form and Motion Simulation

A BETTER UNDERSTANDING of human motion characteristics has long been a goal of researchers in the area of kinesiology (2, 3). The application of high speed cinematography techniques for data collection and the more recent use of the digital computer for data reduction have greatly increased our knowledge of how man moves.

Recently researchers in the area of human motion analysis have been experimenting with the use of the computer not only to analyze cinematographic records but also to assist in obtaining information about certain characteristics of human motion which cannot be observed on film. Studies have attempted to describe accurately the displacement, velocity, and acceleration characteristics of particular body segments during isolated motions. More recent studies have involved comparisons of individual segment energies and their contribution to the motion of the body as a whole (1).

In reviewing this research, it has become clear that many of the problems facing researchers in human motion analysis are the same problems to which engineers working in the field of kinematics have addressed themselves for some time. With this fact in mind, it would seem quite logical to view motion problems from a kinematician's point of view.

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The purpose of this paper is threefold: a) to develop the assumptions necessary to classify the human body as an engineering system; b) to create a three-dimensional computer model of the human body, employing computer graphics techniques to display the model; and c) to apply motion techniques to the model and simulate a given motion.

The body — an engineering view

An understanding of the body's material properties was one of the first steps in developing a model for this system. Each human body segment is composed of many materials with vastly differing physical properties. The skeleton, however, is the framework upon which the entire body is constructed, and although many other tissues may add rigidity, the strength of each body segment is directly proportional to the strength of the bones forming that particular segment (3, 4). Tensile and compressive tests on long bone show that over the normal range of stresses to which bone is subject in everyday use the resulting strain is small. Based on this fact, a first assumption is that all body segments containing continuous long bones will be considered completely rigid for modeling purposes. For instance, the forearm will be considered a rigid segment or link because of the radius and ulna.

Other body segments such as the hands, feet, and trunk are not constructed around continuous long bones and do not fit under the above assumption. However, to avoid

unnecessary complexity in the first models these additional segments will also be assumed rigid.

The human joint

A joint or articulation will be defined as the articulation between two bones. The emphasis in motion analysis is of course placed on the synovial or freely moveable joints. Almost every synovial joint in the human body has a very complex three-dimensional movement over its range of motion. For instance, the knee, although appearing to have a purely hinged or revolute type of motion, is quite complex. The primary motion is indeed revolute in nature. The axis of rotation, however, is in constant motion itself. In short, the problem of correctly modeling the synovial joints is a major undertaking itself and is beyond consideration at this point in the modeling process. Therefore, each of the major synovial joints of the body will be replaced with one of two engineering joints. The two joints are a pure revolute joint and a pure spherical joint. The knee, for example, will be replaced by a revolute joint and the shoulder by a spherical or ball-and-socket joint.

A three-dimensional model

The surface of the human body must be classed as a very complex, highly irregular geometric contour. To make matters worse, not only does the body shape of an individual vary with age, but body shape from individual to individual is highly irregular. Compounding the situation even further is the fact that as an individual moves, his body changes shape slightly. This occurs because of the movement of the bones and muscles supporting the outer layer of the body. All these facts combine to make a good model of the human body very difficult to achieve.

The first attempt at representing the human body in three dimensions was done with little regard for aesthetics. Much more attention was paid to the selection of the body segments that would be considered solid. Considerable attention was also paid to the individual origin and coordinate system by which each segment was defined. Each body segment was represented by some convex polyhedra which roughly simulated that particular segment. As an example, the forearms were represented by rectangular polyhedra. Rectangular polyhedra were chosen because they were the simplest three-dimensional solids which roughly simulated the forearms. In this manner, experience in the definition, manipulation, and visualization of a three-dimensional model was gained without the problems involved in storing and using thousands of data points.

The body was divided into 13 solid segments and each segment was defined with respect to its own origin and coordinate system. The body segments considered solid for this first model were the head, neck, trunk, the arms, the forearms, the thighs, the legs, and the feet. Each of these segments had an origin established at one end of the segment representing the particular synovial joint characteristic to the region of the body in question. Following this format, the leg was defined with respect to an origin representing the knee articulation. The proper placement of all such origins with respect to some fixed Cartesian coordinate system resulted in a three-dimensional model of the human form. A three-dimensional model created in this manner is shown in Figure 1, which shows a right side view and front view, respectively, of the model in its initial position. Initial position refers to the fact that each body segment is stored in this orientation permanently by the computer.

Motion simulation

Since each body segment was defined and stored completely separate from all other segments, and each segment was defined with respect to the joint about which it rotates in the body, motion simulation was quite simple. Each body segment was given a command to rotate about some axis through its origin. Following these rotations, each segment origin was given a command to translate to some point in the fixed coordinate system. With the proper axis of rotation, angles of rotation, and translation of

origins, the human form model could be moved from its initial position to some new orientation. The initial position was defined as that position shown in Figure 1.

The points describing the human body in a three-space were assigned values corresponding to a right-hand Cartesian coordinate system, x,y,z. Letting $\bar{u}$ be a unit vector in the direction of some axis of rotation which passes through the origin of the coordinate system, a rotation matrix [R] may be defined as follows:

$$[R] = \begin{bmatrix} (\mu_x^2 \text{vers}\phi + \cos\phi) & (\mu_x\mu_y \text{vers}\phi - \mu_z \sin\phi) & (\mu_x\mu_z \text{vers}\phi + \mu_y \sin\phi) \\ (\mu_x\mu_y \text{vers}\phi + \mu_z \sin\phi) & (\mu_y^2 \text{vers}\phi + \cos\phi) & (\mu_y\mu_z \text{vers}\phi - \mu_x \sin\phi) \\ (\mu_z\mu_x \text{vers}\phi - \mu_y \sin\phi) & (\mu_y\mu_z \text{vers}\phi + \mu_x \sin\phi) & (\mu_z^2 \text{vers}\phi + \cos\phi) \end{bmatrix}$$

where:

ϕ = angle of rotation

$$\text{vers}\phi = 1 - \cos\phi$$

$$\overline{\mu} = (\mu_x\bar{i} + \mu_y\bar{j} + \mu_z\bar{k})$$

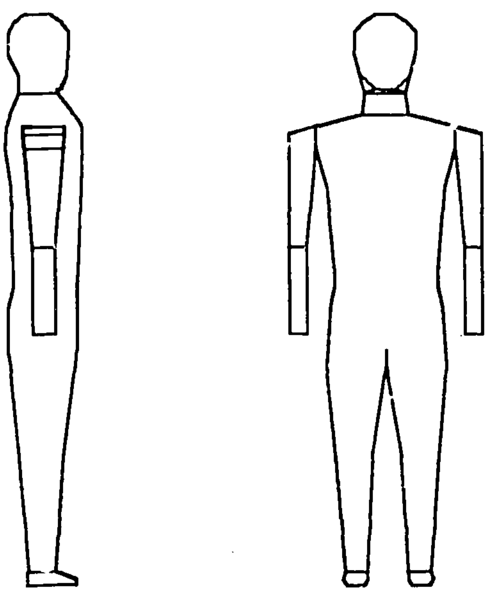

Figure 1. Front and side view of three-dimensional human model.

Positive angles of rotation are defined according to the righthand screw rule.

A point may be rotated about an axis whose direction is specified by μ and through some angle ϕ in the following manner:

$$[V'] = [R]\ [V]$$

where:

[V] = vector describing point to be rotated, $\begin{bmatrix} x \\ y \\ z \end{bmatrix}$

[V'] = rotated vector, $\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix}$

[R] = rotation matrix

The translation of body segment origins was an operation requiring only the use of selected visualization routines. The routines which were used for graphic display provide for the translation of a point from one position to another.

Combining the rotation and translation techniques described above and applying them to the three-dimensional model produced the motion simulation shown in Figure 2. This figure shows a sequential record of the motion characteristics of a subject during a jump from an elevated platform. This view was chosen because it corresponds to the view of the motion captured by the camera for data collection. However, since this is a three-dimensional simulation, any other view of the motion could be displayed with equal ease.

A detailed three-dimensional model

Following the successful application of three-dimensional motion techniques to a human model, a more comprehensive description of the human body was initiated. The surface of the human body, as mentioned earlier, is highly irregular and complex. Because of this fact, any detailed representation of the body form using discrete data would involve a large number of points.

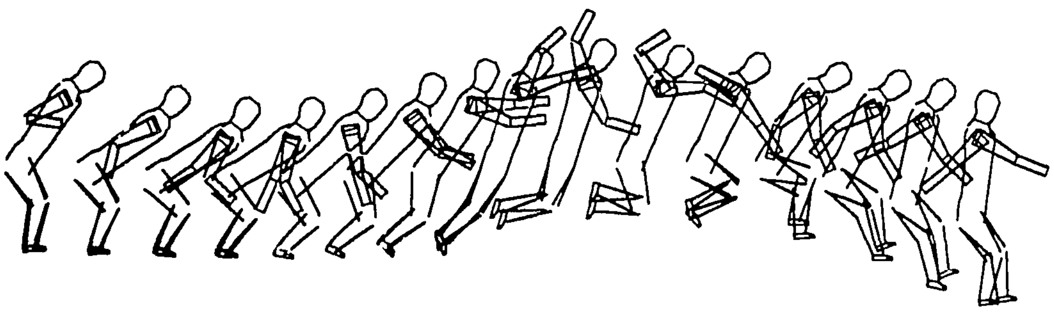

Figure 2. Motion simulation using the three-dimensional human model.

Visualization

The scheme chosen for representing the surface of the body in three dimensions was to define a series of parallel, transverse cross sections. Each point describing the surface of the body was then fixed in the three-space by recording the vertical position of each cross section. Figure 3 shows a model created in this manner. Since this model is a three-dimensional representation of the human body, Figure 3 represents only one of an infinite number of possible views of the model.

A promising tool for researchers in the area of kinesiology is the ability to isolate and study any body segment. An example of this isolation technique can be seen in the views of the head as shown in Figure 4. The head and shoulder areas are shown being rotated around an axis lying in the picture plane.

This three-dimensional model is in the early stages of development with major problems remaining in the areas of visualization and motion.

Conclusions and recommendations

The human form and motion models developed in this paper form a basis on which to construct a more sophisticated and useful model. However, many problems have been encountered during these simulations and remain to be solved prior to the development of any new model. One such problem is in the area of graphic visualization.

The hidden-line problem makes it very difficult to distinguish one surface from another on a three-dimensional solid. Without a hidden-line removal technique, the entire image of an object is projected onto the picture plane as though the object were transparent. Because this projection is monoscopic in nature, and because the front and rear surfaces of the three-dimensional object are displayed simultaneously, the visualization may become unrecognizable. This becomes especially true if the observer is unfamilar with the particular view he is seeing. For instance, if the detailed three-dimensional model of the human form shown in Figure 3 was rotated so that an observer would be looking down across the body from an approximately vertical position, the surfaces of the body would become very difficult to distinguish. The difficulty occurs because the body is very rarely viewed from this position.

To solve this problem would require the use of a rather sophisticated hidden-line removal technique. A technique to handle this problem is near completion at the present time.

Another area in which problems have been encountered is the area of measurement and data collection. Current measurement techniques employ the use of markers attached to the skin or tight garments to fix the position of particular joints during motion of the body. Since the skin and underlying layers of the body shift somewhat dur-

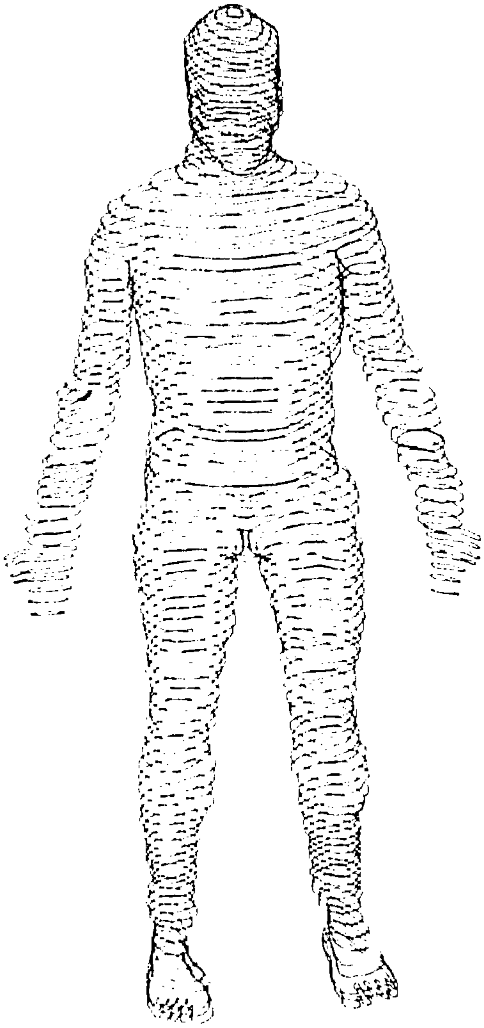

Figure 3. Detailed three-dimensional human model.

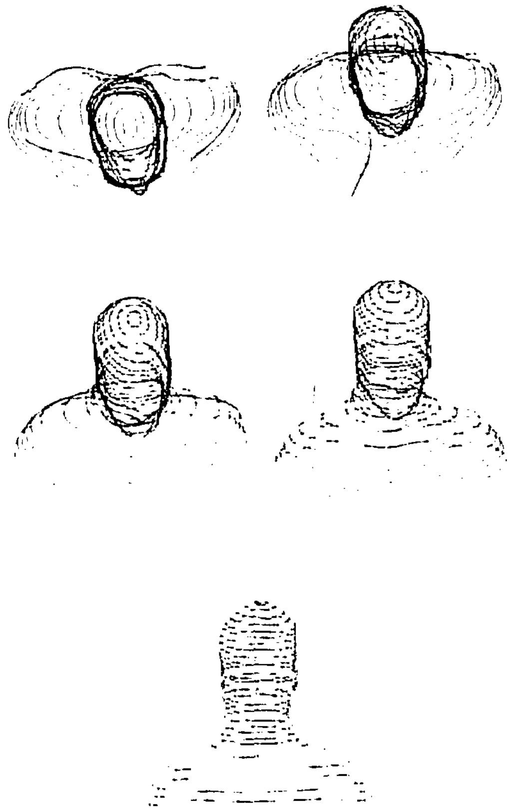

Figure 4. Study of the head and shoulder regions of the detailed three-dimensional model.

ing motion of the body it is very difficult to record the position of any joint precisely. Precise techniques for data reduction and modeling are of little value if the raw data do not correctly define the motion of the body. Time and effort will be needed in this area if the form and motion models are to be realistic.

Further efforts at describing the surface and motion characteristics of the human body should be made by isolating each of the solid body segments. Each of these segments and the joints that connect them should be approached as a separate modeling problem. A better mechanical description of each joint, including inherent stops and some dynamic characteristics, should be included in this phase of the modeling process.

New methods of displaying existing form data should be approached using the cathode-ray tube because of the instantaneous display capabilities of this device. At the same time, an effort should be made to reduce visualization problems caused by the hidden-line problem.

The application of three-dimensional motion routines to the model should follow the development phase outlined above. A set of motion commands coupled to these motion routines would enable a researcher to produce any desired motion of which the model was capable.

A final phase of development should be aimed toward making the size and shape of the model adjustable. By adding scaling routines the model could be tailored to represent any individual. Pathological defects could also be created in the model to serve as a research tool in the area of biomechanics.

The successful development of these modeling phases should yield a good working model of the human body which would serve researchers in the areas of kinesiology, biomechanics, and human factors engineering.

References

1. Garrett, Gladys E., and Widule, Carol J. Kinetic energy: A measure of movement individuality. *Kinesiology Review 1970.*
2. Rasch, Philip J., and Burke. Roger K. *Kinesiology and applied anatomy*. Philadelphia: Lea & Febiger, 1967.
3. Steindler, Arthur. *Kinesiology of the human body*. Springfield, Ill.: Charles C. Thomas, 1964.
4. Sweeney. A. W.: Kroon, R. P.: and Byers, R. K. *Mechanical characteristics of bone and its constituents*. Publication 65-WA/HUF-7, American Society of Mechanical Engineers, New York, 1965.